PROCEEDINGS

*Thirteenth Annual*

# Fertilizer Research & Education Program Conference

FREP

November 30, 2005
National Steinbeck Center, Salinas, California

*Thirteenth Annual*

# Fertilizer Research and Education Program Conference

**November 30, 2005**
**National Steinbeck Center**
**Salinas, California**

*Sponsored By*

California Department of Food and Agriculture

Western Plant Health Association

California Certified Crop Advisor Program

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FREP

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| 8:40 - 9:00 | Governmental Update<br>*Renee Pinel, President, Western Plant Health Association* |
| 9:00 - 9:40 | Vegetable Fertilization in California<br>*Timothy Hartz, UC Davis, Department of Vegetable Crops* |
| 9:40 - 10:00 | New Fertilizing Materials<br>*Robert Mikkelsen, Potash and Phosphate Institute* |
| 10:00 - 10:15 | BREAK |
| 10:15 - 10:45 | Development of BMPs for Fertilizing Lawns to Optimize Plant Performance and Nitrogen Uptake While Reducing the Potential for Nitrate Leaching<br>*Robert Green, UC Riverside, Department of Botany and Plant Sciences* |
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## Crop and Nutrient Management Session

| | |
|---|---|
| 12:45 – 1:15 | Seasonal Patterns of Nutrient Uptake and Partitioning as a Function of Crop Load of the 'Hass' Avocado and Rate of Fertilization<br>*Carol Lovatt, UC Riverside, Department of Botany and Plant Sciences* |
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| 1:45 – 2:00 | BREAK |
| 2:00 – 2:30 | Planning Application Rates for Organic Fertilizers<br>*David Crohn, UC Riverside, Department of Soil and Environmental Sciences* |
| 2:30 – 3:00 | Ammonia Emission Related to Nitrogen Fertilizer Application Practices<br>*Charles Krauter, CSU Fresno, Center for Irrigation Technology* |

## Pesticide and Water Quality Management Session

| | |
|---|---|
| 12:45 – 1:15 | Effective Choices for Disease Control<br>*Ann Chase, Chase Research Gardens* |
| 1:15 – 1:45 | Update on the Agricultural Irrigation Return Flow Waiver<br>*Central Coast Regional Water Quality Board* |
| 1:45 – 2:00 | BREAK |
| 2:00 – 2:30 | Using Polyacrylamide (PAM) for Controlling Sediments and Nutrients in Irrigation Runoff from Central Coast Vegetable Fields<br>*Michael Cahn, UC Cooperative Extension* |
| 2:30 – 3:00 | Effects of Conservation Tillage on Nutrient Losses to Runoff in Alternative and Conventional Farming Systems<br>*William Horwath, UC Davis, Department of Land, Air and Water Resources* |

# FERTILIZER RESEARCH AND EDUCATION PROGRAM INFORMATION

The Fertilizer Research and Education Program (FREP) provides growers and industry with cost-effective ways to improve the efficient use of fertilizers that minimize environmental impacts. FREP serves growers, agricultural supply and service professionals, extension personnel, public agencies, consultants, and other interested parties. FREP is entirely funded from a mill tax on the sale of commercial fertilizers in the State of California, which in turn has provided grants to fund more than 100 research and educational projects over the past 15 years.

FREP was created in 1990 through legislative efforts with support from the fertilizer industry. The California Food and Agricultural Code Section 14611(b) allows CDFA to increase the mill tax on fertilizers in order to provide funding for research projects that support improved farming practices, reducing nitrate contamination of groundwater, as well as any environmental impacts.

Initially, the growing concern of nitrate contamination from fertilizers was FREP's focus. This involved identifying and prioritizing the most nitrate-sensitive groundwater areas in California and working with public agencies, growers, and industry to develop and promote effective ways to reduce nitrate contamination from fertilizers. FREP continues to fund research on reducing nitrate contamination of groundwater, as well as many of California's important environmentally sensitive cropping systems.

## CURRENT FREP FUNDING PRIORITIES

- Projects that determine or update nutrient requirements to improve crop yield or quality in an environmentally sound manner will be considered. Projects may include: research on crop nutrient uptake; the amounts, timing, and partitioning of nutrients removed from the soil; effects of soil chemistry on nutrient uptake; establish or update soil or tissue nutrient level thresholds used to determine fertilizer application timing and/or amounts; and the role of balanced nutrition in improving crop yield/quality.

- Projects that develop fertilization practices to improve crop production, fertilizer use efficiency or environmental impacts will be considered. Projects may include: research on slow-release fertilizers; foliar nutrient management; timing and effectiveness of fertilizer applications; new fertilizer technologies; and nutrient movement in differing soil types, cropping systems, and application methodologies.

- Projects that develop and extend information on fertigation methodologies leading to maximum distribution uniformity and minimizing fertilizer losses will be considered. Other approaches that will reduce ground and surface water contamination or improve the efficiency of fertilizing materials with respect to water management will also be considered.

- Demonstrate and quantify applications for site-specific crop management technologies and best management practices related to precision agriculture. Projects may include: development of fertilizer yield response and utilization models based on spatial and temporal variability; identify and quantify environmental interactions (soil quality issues, soil type characteristics, soil fertility or irrigation variability) and economic relationships.

- Field and laboratory tests for predicting crop nutrient response that can aid in making fertilizer recommendations. New techniques and diagnostic tools for monitoring soil and plant nutrient status are also encouraged. Field correlation studies may also be appropriate.

- Projects may demonstrate or provide practical information to growers and production consultants on nutrient/pest interactions. Pests may include insects, weeds or diseases.

- Educational and public information projects:
  - On-farm demonstrations of proven practices and technologies within FREP goals to encourage their adoption in California, with priority areas given to impaired water bodies.

– Education training of fertilizer management in areas with impaired water bodies.
– Programs to educate growers, fertilizer dealers, students, teachers, and the general public about the relationships between fertilizers, food, public health, and the environment.
– Preparation of publications, slide sets, videotapes, conferences, field days, and other outreach activities.

- Other projects that support FREP's mission, such as air quality, tillage, crop rotation, economics of fertilizer use, and cropping systems will be considered.

### FIGURES 1-3: FREP PROJECT FUNDING

*These figures illustrate the variety of geographical regions, commodities, and disciplines covered by FREP projects over the past 15 years.*

**Figure 1. CDFA FREP Projects by Location: 1990-2005**

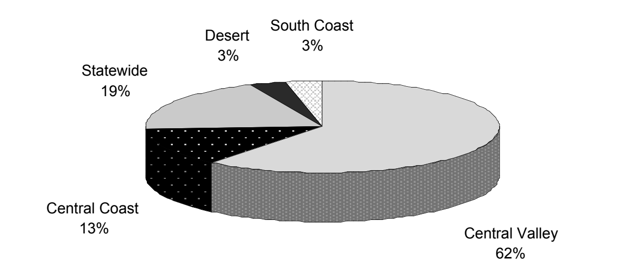



**Figure 2. CDFA FREP Projects by Discipline: 1990-2005**

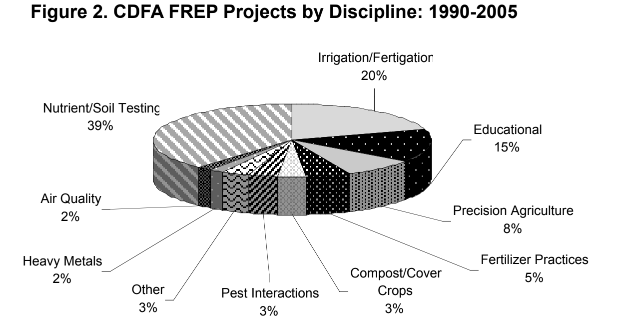
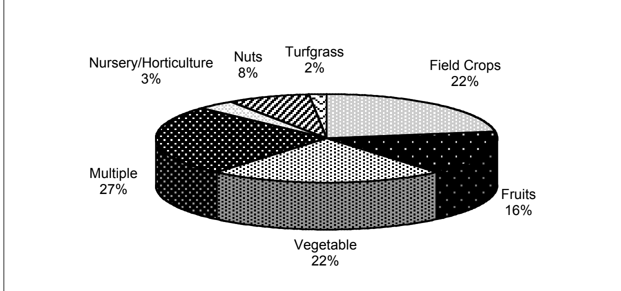



**Figure 3. CDFA FREP Projects by Commodity: 1990-2005**




## EDUCATION AND OUTREACH

One of FREP's primary goals is to ensure that research results generated from the program are distributed to, and used by, growers and the fertilizer industry. This is reflected in significant FREP support (15%) of relevant education and outreach projects (Figure 2). FREP serves a broad audience, including growers, agricultural supply and service professionals, extension personnel, public agencies, consultants, Certified Crop Advisers, Pest Control Advisers, and other interested parties. Proceedings from the annual FREP conference are disseminated throughout the year to interested members of the agricultural community. FREP has also funded a number of projects designed to increase the agricultural literacy of students in the K-12 setting.

In today's world of limited budgets, we know we must work with others to achieve our objectives. To that end, FREP staff collaborates and coordinates with other organizations with similar goals. Our partners include:

- The Western Plant Health Association
- California Chapter of the American Society of Agronomy
- California Certified Crop Adviser Program
- California Association of Pest Control Advisers
- Monterey County Water Resources Agency
- University of California, Sustainable Agriculture Research and Education Program
- State Water Resources Control Board, Interagency Coordinating Committee
- University of California Cooperative Extension Program

## ACKNOWLEDGMENTS

We would like to acknowledge the support of the fertilizer industry in providing funds for the program. Their foresight

in creating FREP and their long-term commitment and dedication has been instrumental in the program's success.

We would also like to recognize the members of the Fertilizer Inspection Advisory Board Technical Advisory Subcommittee, who review and recommend projects for funding. Tom Beardsley, Michael Cahn, Bob Fry, Tom Gerecke, David McEuen, Eric McGee, Rob Mikkelsen, Jerome Pier, Al Vargas, and Jack Wackerman have been invaluable in helping to ensure FREP's success. Their dedication to the program and professionalism is greatly appreciated. The members of the Fertilizer Inspection Advisory Board are also acknowledged for their enthusiastic support and ongoing commitment to the program.

We also greatly value the input and support received from the Western Plant Health Association. Others deserving mention include the project leaders and cooperators, as well as the dozens of professionals who review project proposals and help enhance the quality of FREP's work.

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Nate Dechoretz, Director of the Division of Inspection Services and Kent Kitade, Program Supervisor of the Feed, Fertilizer, and Livestock Drugs Regulatory Services Branch. Joshua Fenrich and JoAnn Jaschke are recognized for their invaluable role in the publication of the Proceedings and the success of the FREP Conference. Additional support from the Branch's clerical staff is also appreciated.

# Development of BMPs for Fertilizing Lawns to Optimize Plant Performance and Nitrogen Uptake While Reducing the Potential for Nitrate Leaching

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## Introduction

The problem addressed by this project is potential nitrate ($NO_3^-$-N) contamination of groundwater caused by fertilization of the approximate 679,426 acres of residential yards in California. Residential yards are the largest component of urban landscapes, and lawns are the largest component of residential yards. Thus, a project involving the development of best management practices (BMPs) for fertilizing lawns to optimize plant performance and N uptake while reducing the potential for $NO_3^B$-N leaching focuses on a potential urban source of $NO_3^B$-N contamination of groundwater. Since the project involves research sites in southern and northern California and will be on tall fescue, the most widely used lawn grass in California, the impact of this project will be on a statewide basis.

Petrovic prepared a review paper entitled, "The fate of nitrogenous fertilizers applied to turfgrass." He summarized 11 papers on $NO_3^B$-N leaching from fertilizers applied to turfgrass. He concluded that leaching of fertilizer N applied to turfgrass has been shown to be highly influenced by soil texture, N source, rate and timing, and irrigation/rainfall. If a significantly higher than normal rate of a soluble N source is applied to a sandy turfgrass site that is highly irrigated, significant $NO_3^B$-N leaching could occur. However, limiting irrigation to only replace moisture used by the plant, using slow-release N sources, and using less sandy soils will significantly reduce or eliminate $NO_3^B$-N leaching from turfgrass sites. Other research has shown that there is a negligible chance of $NO_3^B$-N leaching from turf. However, these findings are normally conditional as follows: water soluble fertilizers are not applied in excess; sandy soils are not heavily irrigated; turf is well-maintained using standard agronomic practices, including judicious use of fertilizers and irrigation; the turfgrass is not immature and the soil is not disturbed, such as during establishment; and root absorption is not low because of dormancy, stress, or because of unhealthy turfgrass. In reality, home lawn owners may cause $NO_3^{B}$-N contamination of groundwater because they do not meet all the conditions that are required to not cause $NO_3^{B}$-N contamination of groundwater.

This project will add to our current understanding of $NO_3^{B}$-N leaching from turfgrass because we have not been able to find any work with tall fescue. Therefore, the information on tall fescue will be new, especially determining the best way to fertilize tall fescue (rate and source) for optimal plant performance and N uptake while reducing the potential for $NO_3^{B}$-N contamination of groundwater. This project also will be new because very little work has been conducted on $NO_3^{B}$-N leaching from turfgrass in California. Most of the work in California has been conducted under golf course turfgrass conditions.

## OBJECTIVES

The objectives of the research project are to 1) evaluate the annual N rate and source on tall fescue to determine which treatments optimize plant performance and N uptake while reducing the potential for $NO_3^{B}$-N leaching; 2) quantify the effect of N fertilizer rate and source on visual turfgrass quality and color; clipping yield, concentration of N in clipping tissue, and N uptake; concentration of $NO_3^{B}$-N and $NH_4^{+}$-N in leachate at a depth below the root zone; and concentration of $NO_3^{B}$-N and $NH_4^{+}$-N in soil; 3) develop BMPs for lawns under representative irrigation practices to optimize plant performance and N uptake while reducing the potential for $NO_3^{B}$-N leaching; and 4) conduct outreach activities, including oral presentations and trade journal publications, emphasizing the importance of the BMPs and how to carry out these practices for N fertilization of lawns.

## DESCRIPTION

The project is being conducted at two sites with different climates and turfgrass maturity, but which are being maintained similarly. One site is a newly established tall fescue plot (sodded late Sept. 2002) in northern California at UC Davis and the other is a mature tall fescue plot (seeded Apr. 1996) in southern California at UC Riverside. Both sites were established to tall fescue, since it is the most widely used lawngrass in California, especially for urban landscapes. The plots at both sites are being irrigated at 110% CIMIS $ET_o$ (California Irrigation Management and Irrigation System), with the amount of irrigation determined weekly based on the previous seven days= cumulative CIMIS $ET_o$ (rainfall may cause the cancellation of irrigation events). There are three irrigation events per week, which are cycled to prevent runoff. The experimental design at both sites is a randomized complete block (RCB) design with N treatments arranged in a 4H3 factorial (four N sources and three rates; see Table 1). A no-nitrogen check treatment is also included to allow for additional statistical comparisons. Nitrogen treatments are being applied from 15 Oct. 2002 to 15 Aug. 2004 at UC Riverside and from 15 May 2003 to 15 Oct. 2005 at UC Davis.

**Table 1. Protocol for 13 N fertilization treatments for the CDFA-FREP study (four N sources x three rates plus a no-nitrogen check).**

| Date of application | N source[z] ($N$-$P_2O_5$-$K_2O$) | Rate (lb N/1000 $ft^2$) a | b | c |
|---|---|---|---|---|
| 1 Mar. | No nitrogen check | 0.0 | 0.0 | 0.0 |
| | A. Ammonium nitrate 34-0-0 | 1.0 | 1.5 | 2.0 |
| | B. Polyon 43-0-0 | 1.0 | 1.5 | 2.0 |
| | C. Milorganite 6-2-0 | 1.0 | 1.5 | 2.0 |
| | D. Nutralene 40-0-0 | 1.0 | 1.5 | 2.0 |
| 15 May | No nitrogen check | 0.0 | 0.0 | 0.0 |
| | A. Ammonium nitrate 34-0-0 | 1.0 | 1.5 | 2.0 |
| | B. Polyon 42-0-0 | 1.0 | 1.5 | 2.0 |
| | C. Milorganite 6-2-0 | 1.0 | 1.5 | 2.0 |
| | D. Nutralene 40-0-0 | 1.0 | 1.5 | 2.0 |
| 15 Aug. | No nitrogen check | 0.0 | 0.0 | 0.0 |
| | A. Ammonium nitrate 34-0-0 | 1.0 | 1.5 | 2.0 |
| | B. Polyon 42-0-0 | 1.0 | 1.5 | 2.0 |
| | C. Milorganite 6-2-0 | 1.0 | 1.5 | 2.0 |
| | D. Nutralene 40-0-0 | 1.0 | 1.5 | 2.0 |
| 15 Oct. | No nitrogen check | 0.0 | 0.0 | 0.0 |
| | A. Ammonium nitrate 34-0-0 | 1.0 | 1.5 | 2.0 |
| | B. Polyon 43-0-0 | 1.0 | 1.5 | 2.0 |
| | C. Milorganite 6-2-0 | 1.0 | 1.5 | 2.0 |
| | D. Nutralene 40-0-0 | 1.0 | 1.5 | 2.0 |
| Total | No nitrogen check | 0.0 | 0.0 | 0.0 |
| | A. Ammonium nitrate 34-0-0 | 4.0 | 6.0 | 8.0 |
| | B. Polyon 43-0-0 and 42-0-0 | 4.0 | 6.0 | 8.0 |
| | C. Milorganite 6-2-0 | 4.0 | 6.0 | 8.0 |
| | D. Nutralene 40-0-0 | 4.0 | 6.0 | 8.0 |

* Ammonium nitrate is a fast-release, water soluble N source; Polyon is a slow-release, polymer-coated N source; Milorganite is a slow-release, natural organic N source; and Nutralene is a slow-release, water insoluble, methylene ureas N source.

Note: Potassium sulfate (0-0-50) and treble superphosphate (0-45-0) will be applied to all plots at an annual rate of 4.0 lb $K_2O$/1000 $ft^2$ and 3.0 lb $P_2O_5$/1000 $ft^2$.

Rev. 5 Mar. 2004

During the 24-month field phase of this study, several measurements are being collected, including visual ratings, $NO_3^{-}$-N and $NH_4^{+}$-N concentrations of soil water below the root zone, and others (Table 2). Measurements are being taken from Oct. 2002 to Oct. 2004 at UC Riverside and from Dec. 2003 to Nov. 2005 at UC Davis.

**Table 2. Protocol for measurements collected during the CDFA-FREP study.**

| Measurement | Frequency | Method and other comments |
|---|---|---|
| 1. Visual turfgrass quality | Once every 2 weeks | 1 to 9 scale, with 1 = worst quality, 5 = minimally acceptable quality, and 9 = best quality for tall fescue |
| 2. Visual turfgrass color | Same time as turfgrass quality | 1 to 9 scale, with 1 = worst color (brown), 5 = minimally acceptable color, and 9 = best color (dark green) for tall fescue |
| 3. Clipping yield, TKN, and N uptake | Four growth periods, with each period spanning four consecutive weekly clipping yields. All periods start one month following each of the four N-fertility treatment application dates (Table 1). Generally, periods are: 1 Apr. to 30 Apr.; 15 June to 15 July; 15 Sept. to 15 Oct.; and 15 Nov. to 15 Dec. | Weekly clipping yield, representing 7-d growth, is collected from 9.2 $ft^2$ (26% of the total surface area) from each plot with the same mower used for routine mowing, except a specially constructed collection box is attached to the mower. Weekly clipping yields are dried at 60 to 67 ºC in a forced-air oven for 48 h and immediately weighed. Yield reported as $g \cdot m^{-2}$. The four weekly yields within each growth period are pooled by the 52 plots and ground. TKN analysis is conducted at the DANR laboratory located at UC Davis. With appropriate calculations, N uptake during four 4-week growth periods is determined. |
| 4. $NO_3^-$-N and $NH_4^+$-N concentration of soil water below rootzone | Once every 2 weeks | One suction plate lysimeter was installed in each plot so the distal tip of the lysimeter cup is at a depth of 2.5 ft below the soil-thatch layer (approximately 0.6 inch deep). The lysimeters were installed at a 45º angle so the lysimeter cup is below undisturbed soil. They were constructed using high-flow ceramic cups (round bottom neck top cups, 1.9-inch diameter, Soil Moisture Equipment Corp. catalog number 653X01-B01M3) and 2-inch diameter PVC pipe. A vacuum of approximately –40 KPa is applied to the lysimeters 24 h before the leachate sampling day. Samples are acidified to pH 2.4-2.8, frozen, and stored until shipped via next-day air to the DANR Laboratory, then stored at 4 ºC until analyzed for $NO_3^-$-N and $NH_4^+$-N by flow injection analyzer method. Analysis occurs within 28 days of leachate collection. |
| 5. Soil water content | Once every 7 d | Volumetric soil water content is determined from the 0- to 48-inch soil depth zone at the same time each Wednesday using four time domain reflectometry (TDR) sensors (MoisturePoint MP-917 TDR unit with Type 2 probe) installed in four null plots within the research plot. The most recent irrigation event is on Tuesday mornings. |
| 6. $NO_3^-$-N and $NH_4^+$-N concentration in soil | Beginning of study (20 Dec. 2002) and at 12 months (1 Oct. 2003) and 24 months (1 Oct. 2004) after initial fertilizer treatments | Two soil cores are taken from each plot and separated into two soil depth zones for the initial sampling: 0 to 12 inches and 12 to 30 inches. For the second and third sampling, cores are separated into three soil depth zones: 0 to 12 inches, 12 to 24 inches, and 24 to 36 inches. A grid is used to ensure that no part of the plot is sampled more than once for the duration of the study. Cores from each plot are pooled by depth; 6 g soil from each plot and depth zone is immediately placed in 40 ml of 2 M KCl to begin the extraction process. Standard procedures are followed to determine $NO_3^-$-N and $NH_4^+$-N concentration on a dry soil basis. |
| 7. Weather data | Continuous | Data obtained from a CIMIS station located at the UCR Turfgrass Research Project. Soil-temperature data loggers also are installed on the research plot. |
| 8. Statistical procedures (to date) | | Most measured variables are statistically analyzed according to a RCB design with 12 treatments arranged in a 4_3 factorial. When the no-nitrogen check treatment is included, a RCB design is used to analyze all 13 treatments. Overall analyses involved a repeated measures design, with measurement date as the repeated measures factor. |

Rev. 30 Sept. 2005 (RS)

# Results and Discussion

## UC Riverside

This report briefly covers three important measurements that are being taken during this study: visual turfgrass quality ratings, concentration of $NO_3^{B}$-N in leachate, and concentration of $NO_3^{B}$-N and $NH_4^+$-N in soil. A more complete data presentation is available in the reports submitted to CDFA-FREP.

***Visual turfgrass quality ratings***

Visual turfgrass quality ratings measure appearance based on several characteristics that normally include color, texture (leaf width and length), uniformity, and density. It should be noted that each characteristic also could be rated by visual means.

This report covers data and analyses of visual turfgrass quality for 48 rating dates, taken from 6 Nov. 2002 to 8 Oct. 2004 (Fig. 1).

In terms of overall analyses of 13 treatments, all fertilizer treatments were within range of an acceptable tall fescue lawn. This assumes that most people are satisfied with a tall fescue lawn when visual turfgrass quality is within the range of 5.5 to 6.5 (1 to 9 scale, with 1 = worst, 5 = minimally acceptable, and 9 = best tall fescue). Overall visual turfgrass quality ranged from 5.5 for Milorganite at an annual N rate of 4.0 lb/1000 $ft^2$ to 6.2 for ammonium nitrate and Polyon at an annual N rate of 8.0 lb/1000 $ft^2$; the check treatment was 4.8.

In terms of overall analyses of 12 fertilizer treatments, arranged in a 4×3 factorial design, ammonium nitrate and Polyon produced overall visual turfgrass quality of 6.0 while Milorganite and Nutralene produced 5.8 and 5.9, respectively. Also, annual N rates of 8, 6, and 4 lb/1000 $ft^2$ produced overall visual turfgrass quality of 6.1, 5.9, and 5.7, respectively.

In terms of 48 rating dates, all fertilizer treatments resulted in a visual turfgrass quality rating ≥ 5.5 on 50% or more rating dates. Fertilizer treatments that resulted in a visual turfgrass quality rating ≥ 6.0 on 50% or more rating dates included all fertilizer sources at the annual N rate of 8.0 lb/1000 $ft^2$; all fertilizer sources at the annual N rate of 6.0 lb/1000 $ft^2$, except for Nutralene; and only one fertilizer source (ammonium nitrate) at the annual rate of 4.0 lb/1000 $ft^2$.

Figure 1. The effect of 13 treatments on visual turfgrass quality of tall fescue, 6 Nov. 2002 to 8 Oct. 2004.

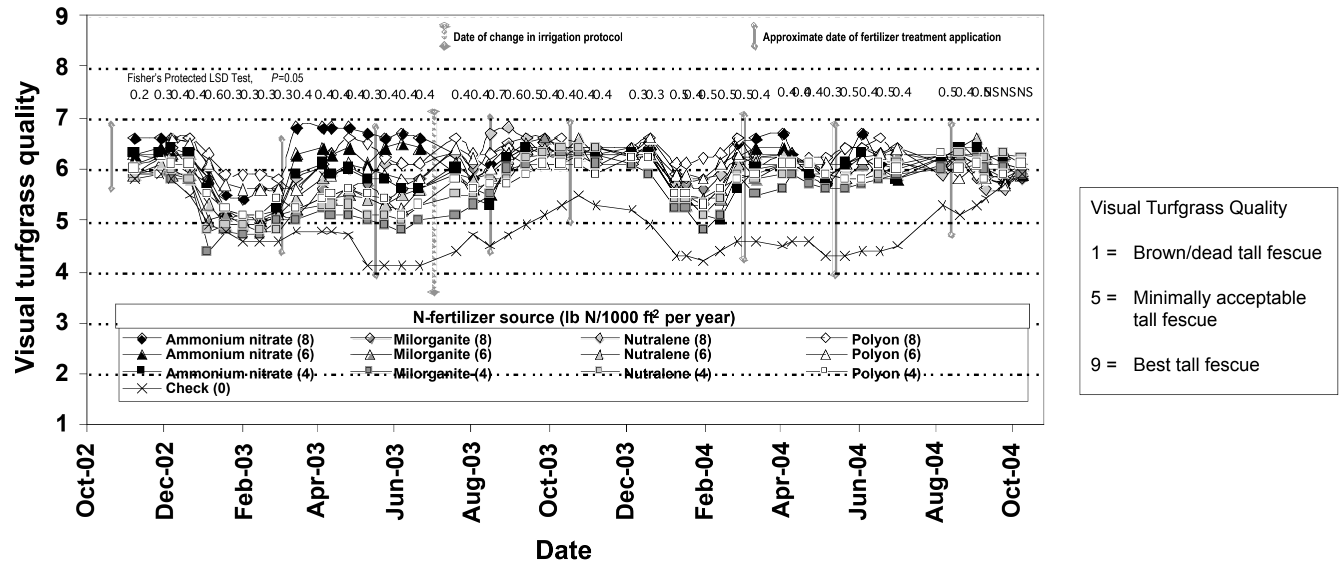
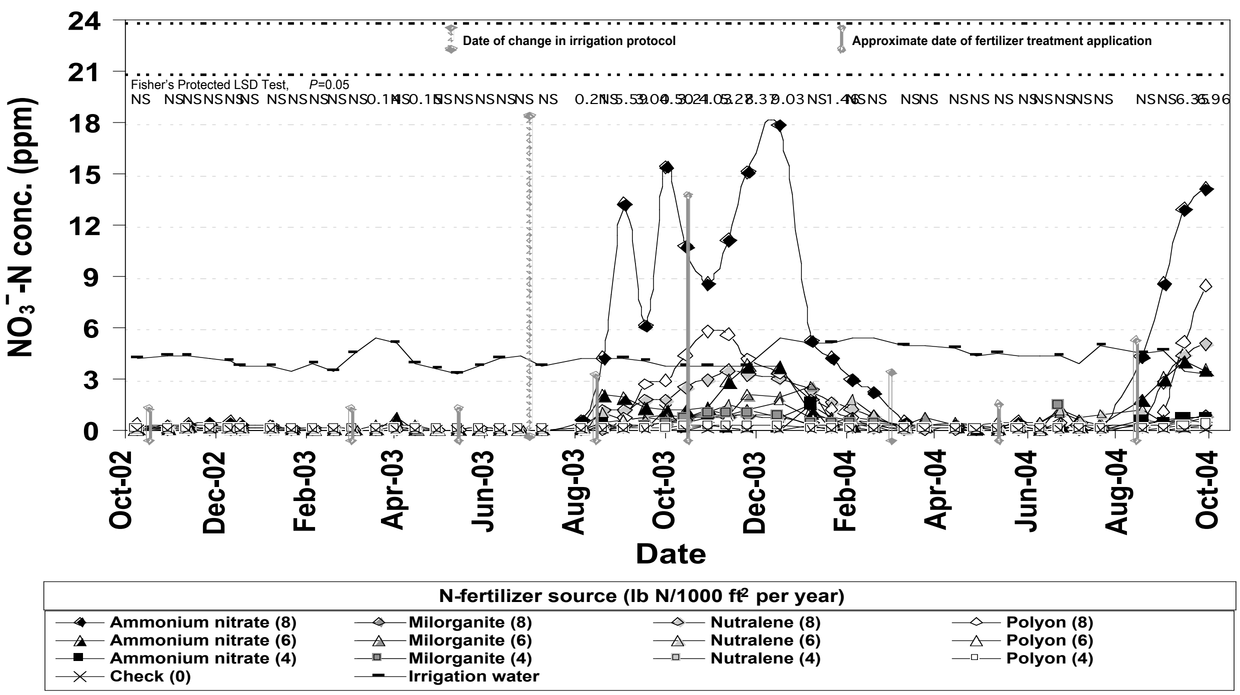



Figure 2. The effect of 13 treatments on $NO_3^-$– N concentration in leachate, 9 Oct. 2002 to 29 Sept. 2004.



***Concentration of $NO_3^-$-N in leachate***

Data for $NO_3^-$-N concentrations in leachate on 48 sample dates from 9 Oct. 2002 to 29 Sept. 2004 are shown in Fig. 2.

These data were affected by a change in irrigation protocol on 2 July 2003. From 16 Oct. 2002 to 1 July 2003, the protocol was (100% $ET_{crop}$/DU) minus rainfall, based on the previous seven-day cumulative CIMIS $ET_o$. The goal of this protocol was to irrigate according to plant water-use needs and not to over-irrigate nor under-irrigate. However, we gradually realized that in making up rainfall, we might have caused some dry soil conditions, especially in the 0- to 6-inch soil depth zone. However, visual drought symptoms were not apparent on all dates, when visual turfgrass quality and color ratings were taken. To alleviate this situation of trying to micromanage a plot that was maintained on the "edge" in terms of plant water use and soil water depletion, we decided to fall back on our historical knowledge of maintaining tall fescue during the summer in Riverside; that is 110% CIMIS $ET_o$, based on the previous seven-day cumulative CIMIS $ET_o$. Thus, we initiated the new irrigation protocol on 2 July 2003 and continued it until the end of the field study, which was 12 Oct. 2004.

During minimalist irrigation from 16 Oct. 2002 to 1 July 2003, $NO_3^-$-N concentrations in leachate were low (< 1 ppm) and differences among fertilizer treatments were basically not significant. It should be noted that the average $NO_3^-$-N concentration of irrigation water was 4.3 ppm.

During well-watered irrigation from 2 July 2003 to 29 Sept. 2004, $NO_3^-$-N concentration in leachate was higher than the previous period. However, concentrations are probably not problematic except for one fertilizer treatment: ammonium nitrate at an annual N rate of 8.0 lb/1000 $ft^2$ (four applications at a N rate of 2.0 lb/1000 $ft^2$). On several sample dates during the months of September through December, $NO_3^-$-N concentration in leachate exceeded 10 ppm. Data also showed significant N source and N rate effects on concentration of $NO_3^-$-N in leachate. Basically, ammonium nitrate and the annual N rate of 8.0 lb/1000 $ft^2$ resulted in the highest concentrations of $NO_3^-$-N in leachate.

These data concerning nitrate leaching, from a well-established tall fescue, will help support BMPs for fertilizing tall fescue lawns to optimize plant performance and nitrogen uptake while reducing the potential for nitrate leaching. Listed below are several observations.

1. Minimalist irrigation reduces the potential for nitrate leaching. However, sufficient irrigation is needed to promote healthy turfgrass.

2. An annual N rate of 4 to 6 lb/1000 $ft^2$ produces an acceptable to good quality tall fescue lawn. Higher rates are normally not necessary and may increase the risk of nitrate leaching.

3. Slow-release N sources (Nutralene, Milorganite, and Polyon) cause less nitrate leaching than a fast-release N source (ammonium nitrate).
4. The amount of nitrate leaching from a fast-release N source can be drastically reduced if N rates of individual applications do not exceed 1.0 to 1.5 lb/1000 $ft^2$.

***Concentration of $NO_3^-$-N and $NH_4^+$-N in soil***

During the beginning of the study (20 Dec. 2002), $NO_3^-$-N concentrations were low (< 1 ppm), fairly uniform across the plots, and slightly higher in the 12- to 30-inch soil depth zone than the 0- to 12-inch soil depth zone. Also, $NH_4^+$-N concentrations were low (< 1 ppm) and slightly higher in the 0- to 12-inch soil depth zone than the 12- to 30-inch soil depth zone.

During one year following fertilizer treatment applications (9 Oct. 2003), $NO_3^-$-N concentrations were low (< 2 ppm) and significantly affected by the 13 fertilizer treatments but not the three soil depth zones (0 to 12 inches, 12 to 24 inches, and 24 to 36 inches). Also, $NH_4^+$-N concentrations were low (normally < 2 ppm) and not significantly affected by the 13 fertilizer treatments but significantly affected by the three soil depth zones; $NH_4^+$-N soil concentrations were highest at the 0- to 12-inch soil depth zone.

During two years following fertilizer treatment applications (6 Oct. 2004), $NO_3^-$-N concentrations were low (< 2 ppm) and significantly affected by the 13 fertilizer treatments and the three soil depth zones. Also, $NH_4^+$-N concentrations were low (< 2 ppm) and not significantly affected by the 13 fertilizer treatments but significantly affected by the three soil depth zones; $NH_4^+$-N soil concentrations were highest at the 0- to 12-inch soil depth zone.

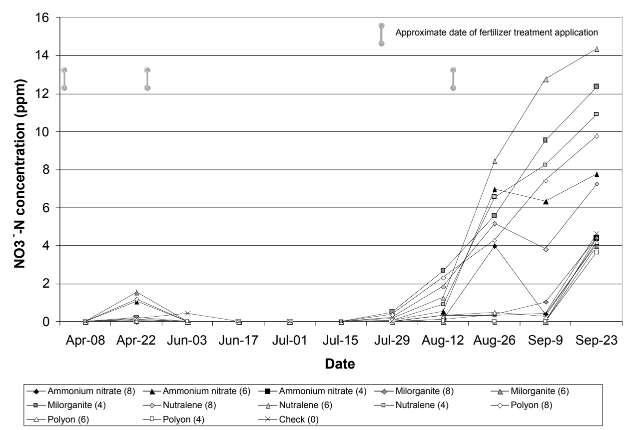
# UC Davis

This report briefly describes the results we obtained during 2005. As in 2004, and even with prophylactic fungicide applications, Rhizoctonia brown patch infested much of the experimental turf plot area during the early- and mid-summer months. This, along with an uneven fertilizer treatment application in May 2005, prevented worthwhile color and quality evaluations. Therefore, our focus was on the regular and routine collection of soil water leachate samples for the analysis of $NO_3^-$-N.

***Concentration of $NO_3^-$-N in leachate***

Data from $NO_3^-$-N concentrations in leachate on 11 sample dates from 8 Apr. to 23 Sept. 2005 are shown in Figure 3.

**Figure 3. The effect of 13 treatments on $NO_3^-$– N concentration in leachate at UC Davis, 8 April to 23 September 2005.**




During this time period, the plots were irrigated using 110% CIMIS $ET_o$ values obtained from a local weather station. Weekly application rates were based on the previous seven-day cumulative CIMIS $ET_o$ values. $NO_3^-$-N concentrations stayed low (under 2 ppm) from April to early August. A slight rise in April in response to the March fertilization was noted. In early August and in advance of the 16 Aug. fertilizer applications, leachate $NO_3^-$-N concentrations began to increase. By mid-to-late September, several treatments had leachate $NO_3^-$-N concentrations near or above 10 ppm. These included: Nutralene (annual N rate of 4.0, 6.0, and 8.0 lb/1000 $ft^2$), Milorganite (annual N rate of 4.0 lb/1000 $ft^2$), Polyon (annual N rate of 8.0 lb/1000 $ft^2$), and ammonium nitrate (annual N rate of 6.0 lb/1000 $ft^2$). Unlike the results at UC Riverside, the highest rate of ammonium nitrate (annual N rate of 8.0 lb/1000 $ft^2$) did not result in high concentrations of $NO_3^-$-N in the leachate. The $NO_3^-$-N concentration of the irrigation water was always below 1 ppm, except for the 23 Sept. analysis when it was 3.2 ppm.

The high $NO_3^-$-N in the leachate from the slow-release fertilizers (Nutralene and Polyon) is of concern. This result was not seen at UC Riverside and will be followed closely at UC Davis until the end of the project (late 2005).

For more information about turfgrasses in California, please see http://ucrturf.ucr.edu.

# Determination of Nursery Crop Yields, Nutrient Content, and Water Use for Improvement of Water and Fertilizer Use Efficiency

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## INTRODUCTION

There is increasing interest in the development of fertilizer and irrigation best management practices for commercial nurseries. Some of the information necessary for the development of BMPs for nurseries is available. For example, some information about water and nitrogen requirements of one-gallon container nursery stock has been published, and a few studies have addressed questions about the effects of fertilizer N form, concentration, and frequency of delivery, and the effects of plant development on nutrient uptake. Although such studies yield much useful information, they are not well suited to provide general guidelines for fertilizer management of the immense range of nursery crops in California. This project was undertaken to provide the nursery industry with basic information about the quantities of nitrogen, phosphorus, potassium, and water needed by their crops.

## OBJECTIVES

1. Determine the NPK uptake of 75 container-grown ornamental crops at commercial maturity.
2. Measure water use of these crops at key stages of development and relate values to reference evapotranspiration.
3. Estimate and prepare recommendations for overall crop water and fertilizer needs based on values obtained from preceding objectives.

## DESCRIPTION

A wide range of nursery crops were grown in the Environmental Horticulture outdoor nursery on the UC Davis campus. Plants were fertilized with a complete controlled-release fertilizer or with a complete liquid feed fertilizer. Fresh and dry weights and NPK contents of the roots and shoots of propagules and finished crops were determined. Evapotranspiration was monitored throughout crop production. Data for Year 1 and part of Year 2 are presented here.

## RESULTS AND CONCLUSIONS

### Year 1

Daily water use of the one-gallon sun and shade crops grown in Year 1 varied with weather conditions and crop age. Water use of plants grown in full sun did not exceed 250 mL/day on any day, and usually was less than 200 mL/day. Water use of plants grown under shade cloth never exceeded 200 mL/day, and usually was less than 150 mL/day. The crop coefficients for crops grown in full sun ranged from 0.9-1.8 (based on water use relative to $ET_o$ for the soil surface area), but seasonal changes in $k_c$ never exceeded 0.29 for a particular shrub species. The values were generally lower for shade-grown species, but remained relatively constant over time for only two of the species. For the other shade-grown species, $k_c$ increased by as much as 0.73 as plants increased in size.

Applied fertilizer rate (low and high rates recommended by the manufacturer) had no significant effect on yields, and these woody species did not appear to have luxury consumption of the macronutrients analyzed. Dry weights and tissue nutrient concentrations of finished plants are presented in Table 1. Four species (Aucuba, Camellia, Dietes, and Juniperus) grew slowly and had relatively small dry weight gains. Tissue nitrogen concentrations were acceptable in all species, but P was low in several species and K was unusually low in Camellia. Camellia took up extremely small amounts of N and no measurable amounts of P or K during the growing season (Table 2). Among the species with more normal growth, N uptake ranged from 70 mg by Aucuba to 598 mg by Lavandula (Table 2). P uptake among most species was between 30-50 mg, but uptake by Aucuba, Camellia, Dietes, and Juniperus was 11 mg or less. K uptake also varied widely.

**Table 1. Dry weight and tissue N, P, and K concentrations in whole plants (shoots plus roots) from 1-gallon containers at commercial maturity in Year 1 experiment.**

| Species | Dry wt. (g) | N (%) | P (%) | K (%) |
|---|---|---|---|---|
| Acorus 'Ogon' | 25.1 | 2.87 | 0.39 | 3.73 |
| Aucuba japonica 'Variegata' | 4.3 | 2.37 | 0.19 | 1.56 |
| Camellia x 'Winter's Star' | 5.2 | 2.07 | 0.15 | 0.64 |
| Dietes vegeta | 8.6 | 1.95 | 0.21 | 2.19 |
| Hydrangea macrophylla 'Nikko Blue' | 24.0 | 2.20 | 0.23 | 2.12 |
| Juniperus scopulorum 'Moonglow' | 11.6 | 2.12 | 0.15 | 1.45 |
| Lantana 'Pink Caprice' | 29.7 | 2.04 | 0.17 | 1.89 |
| Lavandula dentata | 32.4 | 2.05 | 0.19 | 1.92 |
| Nandina domestica | 26.4 | 1.65 | 0.15 | 1.00 |
| Weigela florida 'Variegata Nana' | 14.6 | 2.53 | 0.30 | 1.70 |

**Table 2. Total N, P, and K uptake of plants in 1-gallon containers between planting and harvest in Year 1 experiment.**

| Species | N (mg) | P (mg) | K (mg) |
|---|---|---|---|
| Acorus 'Ogon' | 529 | 53 | 716 |
| Aucuba japonica 'Variegata' | 70 | 3 | 22 |
| Camellia x 'Winter's Star' | 42 | | |
| Dietes vegeta | 132 | 11 | 141 |
| Hydrangea macrophylla 'Nikko Blue' | 449 | 41 | 459 |
| Juniperus scopulorum 'Moonglow' | 138 | 5 | 108 |
| Lantana 'Pink Caprice' | 565 | 44 | 525 |
| Lavandula dentata | 598 | 54 | 557 |
| Nandina domestica | 411 | 33 | 240 |
| Weigela florida 'Variegata Nana' | 311 | 32 | 196 |

Cumulative water use (transpiration plus evaporation) ranged from about 11-15 liters for most species (Table 3). The maximum ratio of N uptake to total water use was 56 mg/l, and the average value was 25 mg/l.

**Table 3. Cumulative water use and calculated minimum liquid feed [N] (based on ratio of total N uptake and total water uptake) in Year 1 experiment.**

| | Low fertilizer rate | | High fertilizer rate | |
|---|---|---|---|---|
| Species | Water use (l) | [N] (mg/l) | Water use (l) | [N] (mg/l) |
| Acorus 'Ogon' | 11.6 | 36 | 13.0 | 49 |
| Aucuba japonica 'Variegata' | 7.8 | 11 | 7.2 | 7 |
| Camellia x 'Winter's Star' | 7.5 | 8 | 7.1 | 2 |
| Dietes vegeta | 11.7 | 10 | 11.1 | 14 |
| Hydrangea macrophylla 'Nikko Blue' | 12.7 | 38 | 11.1 | 38 |
| Juniperus scopulorum 'Moonglow' | 11.5 | 10 | 11.8 | 13 |
| Lantana 'Pink Caprice' | 17.9 | 27 | 18.6 | 34 |
| Lavandula dentata | 15.3 | 32 | 13.3 | 56 |
| Nandina domestica | 10.6 | 31 | 10.6 | 47 |
| Weigela florida 'Variegata Nana' | 15.4 | 22 | 15.0 | 18 |

## Year 2

The experiments in Year 2 were focused on herbaceous species and were grown in containers ranging in size from four-inch to one-gallon, depending on species. The yields differed significantly among species, and the applied fertilizer rate affected yields and nutrient content in coleus, cosmos, and pepper plants (Table 4). Average yield for all species fertilized at the high recommended rate was 14.4 g, compared to 13.3 g for plants fertilized at the low recommended rate.

Shoot N, P, and K concentrations were significantly different among species, and tissue N concentrations were affected by fertilizer concentration, but shoot K and P concentrations were affected only by species (Table 5). The lower N and K concentrations in plants fertilized at the low fertilizer rate could account for the lower yields observed at that fertilizer concentration, although NPK concentrations were within the published acceptable ranges for all species except pepper (and perhaps cosmos, for which no published data are available).

The highest quantity of N uptake was 883 mg by cosmos plants (Table 6). Average N uptake was 346 mg at the low fertilizer rate and 446 mg at the high rate. Fertilizing at the high recommended rate resulted in greater N uptake by coleus, cosmos, impatiens, nepeta, pepper, and perovskia, but only coleus, cosmos, and pepper plants responded with higher yields.

**Table 4. Dry weight (g) of finished plants in Year 2 experiment.**

| | Low fertilizer rate | | | High fertilizer rate | | |
|---|---|---|---|---|---|---|
| Species | Shoot | Root | Total | Shoot | Root | Total |
| Angelonia | 12.7 | 1.30 | 14.0 | 12.0 | 1.14 | 13.1 |
| Calibrachoa | 10.6 | 0.69 | 11.3 | 8.0 | 0.52 | 8.6 |
| Caryopteris 'Longwood Blue' | 14.4 | 0.85 | 15.3 | 14.6 | 0.69 | 15.3 |
| Coleus 'Tilt A Whirl' | 6.9 | 1.06 | 8.0 | 10.1 | 1.10 | 11.2 |
| Cosmos 'Sonata Pink' | 20.7 | 2.16 | 22.9 | 25.5 | 2.56 | 28.1 |
| Geranium 'Flamingo' | 19.9 | 2.09 | 22.0 | 21.9 | 2.07 | 24.0 |
| Impatiens 'Double Ole Rose' | 7.7 | 0.75 | 8.5 | 7.4 | 0.64 | 8.1 |
| Lavender 'Munstead' | 7.0 | 0.55 | 7.6 | 6.1 | 0.63 | 6.7 |
| Nepeta 'Dropmore' | 16.4 | 1.69 | 18.1 | 20.2 | 1.29 | 21.4 |
| New Guinea Impatiens 'Bonfire Orange' | 5.5 | 0.79 | 6.3 | 5.8 | 0.95 | 6.7 |
| Penstemon 'Red Rocks' | 10.3 | 0.33 | 10.6 | 9.2 | 0.28 | 9.4 |
| Pepper 'Sweet California Wonder' | 11.3 | 4.39 | 15.7 | 16.1 | 5.62 | 21.7 |
| Perovskia atriplicifolia | 11.7 | 0.79 | 12.5 | 12.3 | 1.04 | 13.4 |

**Table 5. Whole shoot nutrient concentrations (% dry weight) of finished plants in experiment.**

| | Low fertilizer rate | | | High fertilizer rate | | |
|---|---|---|---|---|---|---|
| Species | N (%) | P (%) | K (%) | N (%) | P (%) | K (%) |
| Angelonia | 3.10 | 0.43 | 2.48 | 3.29 | 0.49 | 2.70 |
| Calibrachoa | 3.46 | 0.42 | 3.37 | 3.46 | 0.42 | 3.35 |
| Caryopteris 'Longwood Blue' | 3.79 | 0.45 | 2.52 | 3.97 | 0.49 | 2.69 |
| Coleus 'Tilt A Whirl' | 3.66 | 0.74 | 4.17 | 3.98 | 0.67 | 4.30 |
| Cosmos 'Sonata Pink' | 2.26 | 0.46 | 3.13 | 3.65 | 0.57 | 4.34 |
| Geranium 'Flamingo' | 2.69 | 0.56 | 3.16 | 2.81 | 0.60 | 3.38 |
| Impatiens 'Double Ole Rose' | 3.56 | 0.62 | 4.15 | 4.28 | 0.63 | 4.41 |
| Lavender 'Munstead' | 3.13 | 0.41 | 4.17 | 3.21 | 0.42 | 4.41 |
| Nepeta 'Dropmore' | 3.62 | 0.45 | 3.60 | 3.97 | 0.45 | 3.75 |
| New Guinea Impatiens 'Bonfire Orange' | 3.09 | 0.58 | 3.29 | 3.42 | 0.62 | 3.15 |
| Penstemon 'Red Rocks' | 2.89 | 0.49 | 3.17 | 2.93 | 0.50 | 3.03 |
| Pepper 'Sweet California Wonder' | 2.62 | 0.52 | 3.78 | 3.20 | 0.45 | 4.25 |
| Perovskia atriplicifolia | 3.10 | 0.56 | 3.88 | 3.61 | 0.59 | 4.09 |

**Table 6. Whole plant nutrient uptake of finished plants in Year 2 experiment.**

| | Low fertilizer rate | | | High fertilizer rate | | |
|---|---|---|---|---|---|---|
| Species | N (mg) | P (mg) | K (mg) | N (mg) | P (mg) | K (mg) |
| Angelonia | 393 | 54 | 304 | 391 | 57 | 310 |
| Calibrachoa | 370 | 45 | 292 | 259 | 35 | 220 |
| Caryopteris 'Longwood Blue' | 545 | 65 | 365 | 581 | 71 | 401 |
| Coleus 'Tilt A Whirl' | 220 | | | 380 | | |
| Cosmos 'Sonata Pink' | 388 | | | 883 | | |
| Geranium 'Flamingo' | 214 | | | 264 | | |
| Impatiens 'Double Ole Rose' | 468 | | | 552 | | |
| Lavender 'Munstead' | 204 | 26 | 257 | 186 | 24 | 228 |
| Nepeta 'Dropmore' | 596 | 74 | 588 | 803 | 91 | 747 |
| New Guinea Impatiens 'Bonfire Orange' | 114 | | | 148 | | |
| Penstemon 'Red Rocks' | 287 | 48 | 306 | 255 | 48 | 259 |
| Pepper 'Sweet California Wonder' | 345 | | | 654 | | |
| Perovskia atriplicifolia | 356 | 65 | 430 | 445 | 73 | 517 |

**Table 7. Cumulative water uptake and calculated minimum liquid feed NPK concentrations (based on ratio of total NPK uptake and total water uptake) in Year 2 experiment.**

| | Low fertilizer rate | | | | High fertilizer rate | | | |
|---|---|---|---|---|---|---|---|---|
| Species | Water use (L) | [N] (mg/l) | [P] (mg/l) | [K] (mg/l) | Water use (L) | [N] (mg/l) | [P] (mg/l) | [K] (mg/l) |
| Angelonia | 3.1 | 128 | 17 | 99 | 3.4 | 116 | 17 | 92 |
| Calibrachoa | 2.7 | 138 | 17 | 109 | 2.7 | 97 | 13 | 83 |
| Caryopteris ‘Longwood Blue’ | 3.1 | 174 | 21 | 117 | 3.2 | 184 | 23 | 127 |
| Coleus ‘Tilt A Whirl’ | 2.0 | 112 | 22 | 123 | 2.1 | 179 | 29 | 186 |
| Cosmos ‘Sonata Pink’ | 3.3 | 119 | 23 | 164 | 3.5 | 253 | 37 | 295 |
| Geranium ‘Flamingo’ | 2.1 | 103 | 17 | 126 | 1.7 | 158 | 21 | 165 |
| Impatiens ‘Double Ole Rose’ | 3.8 | 123 | 28 | 143 | 3.9 | 142 | 33 | 167 |
| Lavender ‘Munstead’ | 2.3 | 89 | 11 | 112 | 2.1 | 87 | 11 | 107 |
| Nepeta ‘Dropmore’ | 4.1 | 146 | 18 | 144 | 3.6 | 224 | 25 | 208 |
| N.G. Impatiens ‘Bonfire Orange’ | 1.6 | 73 | 14 | 77 | 1.6 | 93 | 16 | 79 |
| Penstemon ‘Red Rocks’ | 3.1 | 92 | 15 | 98 | 2.7 | 93 | 18 | 95 |
| Pepper ‘Sweet California Wonder’ | 2.6 | 133 | 24 | 155 | 2.9 | 223 | 29 | 232 |
| Perovskia atriplicifolia | 3.4 | 103 | 19 | 125 | 3.4 | 130 | 21 | 151 |

The calculated ratio of N uptake: water uptake over the course of the experiment indicates that most of these herbaceous species readily take up about 100-150 mg N/l, 20 mg P/l, and 120-150 mg K/l (Table 7). Luxury consumption of N occurs in most of the species tested.

Evapotranspiration did not exceed 250 ml/day, and usually was less than 150 mL/day. Cumulative water use ranged from 1.6 l for New Guinea impatiens to 3.9 l for impatiens (Table 7). Only geranium, cosmos, nepeta, and perovskia, the crops with the greatest leaf area, exceeded $ET_o$. The crop coefficient, $k_c$, tended to increase as plants matured. For most species, $k_C$ did not increase dramatically until the week of harvest. Values in the first two weeks after planting ranged from 0.2 to 0.6 (based on water use relative to $ET_o$ for the area occupied by each plant). At commercial maturity, $k_c$ ranged from 0.4 for New Guinea impatiens to 1.5 for cosmos.

# Precision Fertigation in Orchards: Development of a Spatially Variable Microsprinkler System

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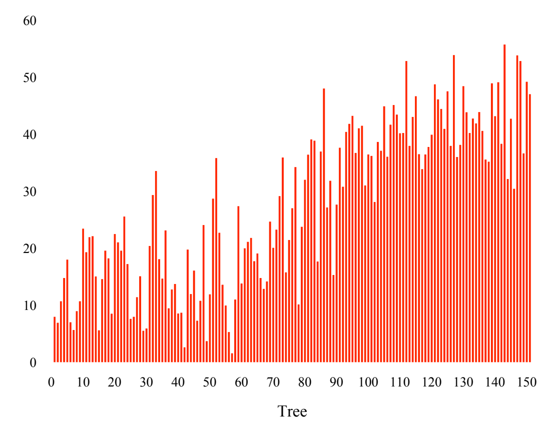
## Introduction

Recent research in pistachio orchards has shown that significant variation in yield occurs among sites within an orchard. Even within a single orchard row, there is substantial yield variability between individual trees (Figure 1). Based strictly on production potential, the lower yielding trees required less water and fertilizer than the field average and the higher yielding trees required more. This represents a loss in productivity since some trees were probably not reaching their full potential. Variability has been quantified using remote sensing (e.g., normalized difference vegetation index, leaf area index), soil sampling, yield monitoring, and growth measurements. Possible causes of variability include tree stress, soil type, water and nutrient availability, diseases and pests, tree size and age, and individual tree genetics. In 2004, the U.S. almond crop was valued at over $2 billion and the pistachio crop was valued at over $400 million. By addressing water and nutrient availability at an individual tree level, we believe that yield, nutrient and water use efficiency, and crop value could be increased. Therefore, there is significant incentive to optimize productivity and profit by bringing each tree to its maximum yield potential.

**Figure 1. The yield of individual pistachio trees along a single orchard row.**



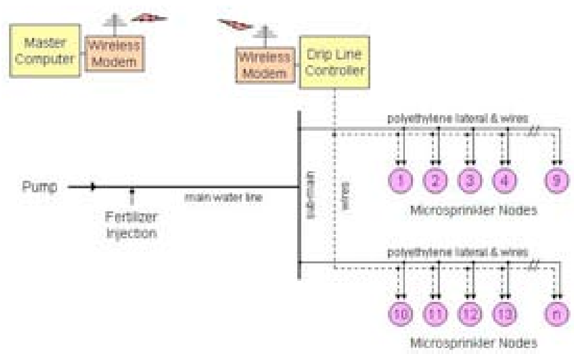

## Objectives

1. Design and develop electronic hardware for individually controllable microsprinklers along a microirrigation line.
2. Develop the communication network and software for control of the microsprinkler network by a drip line controller and master computer.
3. Evaluate control strategies for accurate water/fertilizer application.
4. Develop methods for automated fault detection.

## System Design

The spatially variable microsprinkler system (Figure 2) consisted of three main components: the microsprinkler node, drip line controller, and master computer. Each microsprinkler node had a valve to control water application, independent of all other nodes in the field. The nodes received water through drip irrigation tubing and were powered by a wired network. The drip line controller stored the irrigation schedule and communicated with the individual microsprinkler nodes and master computer.

**Figure 2. Layout of the microsprinkler system with networked microsprinkler nodes, drip line controller, and master computer.**




### *Hardware*

Each node consisted of an electronic circuit, latching solenoid valve, and orchard microsprinkler (Figure 3). The electronic circuit used a simple microcontroller to operate the valve, read sensors, and process commands from the drip line controller. A voltage regulator converted 12 V from the power/signal wires to 5 V for powering the microcontroller. A latching solenoid valve was selected because it required only a brief pulse of current to open or close. The valve inlet was connected to the drip line and the outlet was connected to a microsprinkler rated for 10 gph at 25 psi. The valve was actuated with a 50 ms, 12 V pulse. A boost capacitor stored energy from the power/signal network to assist with valve actuation. This was required to overcome voltage-drop caused by the network wire resistance. The analog-to-digital converter on the microcontroller was used to measure signals from external sensors, including a pressure transducer and soil moisture sensor. The circuit boards were housed in polycarbonate watertight enclosures with sealed ports for the network, valve, and sensor wires.

**Figure 3. Microsprinkler node with circuit connected to power/signal wires, and valve and microsprinkler connected to drip line.**

The drip line controller consisted of an embedded controller, signal buffer, battery, and wireless modem (Figure 4). A liquid-crystal display provided visual feedback during testing and a keypad allowed manual control of the system. The embedded controller stored and executed the irrigation schedule and retrieved sensor data from microsprinkler nodes. Three 14-gauge (AWG) wires (12 V, ground, and signal), each 1000 ft in length, formed the network that interconnected the drip line controller and microsprinkler nodes. The signal buffer translated RS-232 and logic-level signals between the embedded controller and nodes. The drip line controller could be remotely accessed by the master computer through a wireless modem. The entire system was powered by a 12 V lead-acid battery coupled to recharging circuitry with a solar panel.

**Figure 4. The drip line controller consisted of an embedded controller, power supplies with solar charger, signal buffer, and wireless modem.**

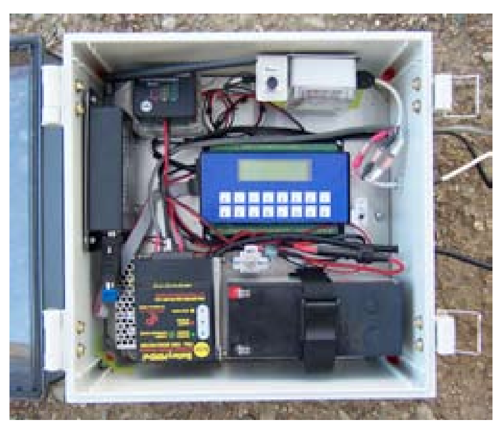


**Figure 5. The node microcontroller program checked for an initiation byte, address, and command, and then replied to the drip line controller after address reception and execution of the command.**

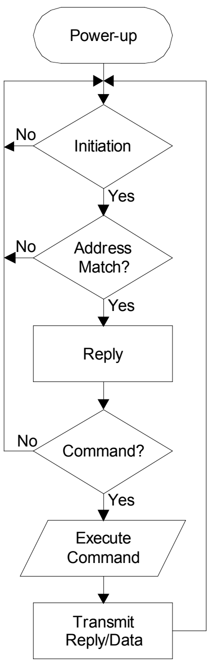
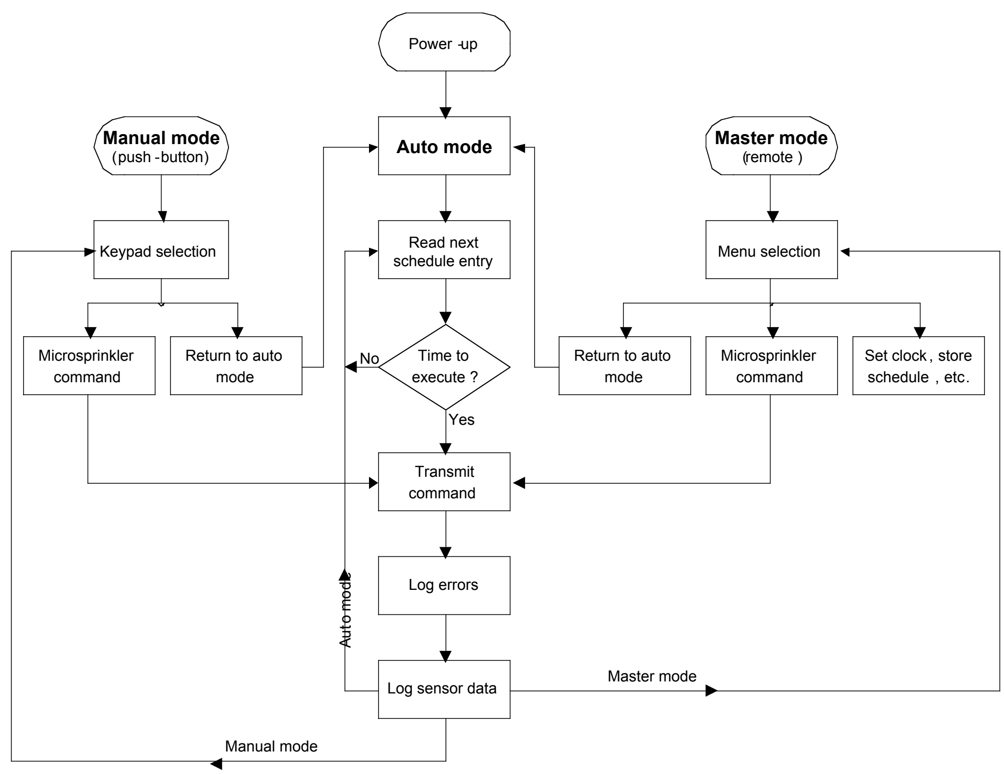



**Figure 6. The drip line controller executed irrigation schedules in auto mode, keypad selections in manual mode, and menu selections in master mode.**



The master computer was a laptop computer that provided an interface for the user to store irrigation schedules, monitor system status, retrieve sensor data, and manually control the network. A small 12 V lead-acid battery powered a wireless modem connected to the laptop serial port. The master computer used a terminal program to remotely interface with the drip line controller. To initiate a session, the user simply opened a connection and pressed any key. This caused the drip line controller to transmit a text-based menu of options. The user could then select an option and follow the on-screen prompts.

***Software***

Each node was individually programmed with one of 254 unique addresses between 1 and 255. Zero was reserved for communication initiation and 256 was used as a broadcasting address. More nodes could be handled by using multiple address bytes. A master-slave protocol was developed in which the drip line controller initiated all communication with the microsprinkler nodes. The protocol included an initiation byte, address byte, and command byte transmitted by the drip line controller, with replies transmitted by the addressed node (Figure 5).

The embedded controller operated in one of three modes: auto, master, or manual (Figure 6). On power-up, the controller entered auto mode and the irrigation schedule stored in memory was executed. Each schedule entry contained a node address, execution time, and command. The command in each entry was transmitted to the appropriate node at the scheduled time. Errors that occurred during communication were recorded in an error log. Data transmitted by the nodes were stored in data logs. The user could suspend auto-mode with the master computer or push-button switch and execute other operations such as storing a new schedule, setting the internal clock, manually sending commands to a specific microsprinkler node, downloading sensor data, or reading the error log.

## Performance Evaluation

Various tests were conducted on a prototype system to evaluate its performance and identify potential problems. Fifty microsprinkler nodes were installed along four rows in a nectarine orchard at the University of California, Davis. Polyethylene drip tubing delivered water to the microsprinklers in each row. The drip line controller was installed at one corner of the orchard and 1000 ft of power/signal wire interconnected it with the microsprinkler nodes. The wire was laid alongside the laterals in each row, buried between rows, and the excess length remained on a spool.

**Figure 7. Prototype system installed at UC Davis with drip line controller, solar panel, battery, network wire, microsprinkler nodes, and water collection buckets.**

***Irrigation Control Strategies***

Three different control strategies were used by the drip line controller: time-control, volume-control, and soil-moisture-control.

The time-controlled field test showed how each microsprinkler was independently controllable and could be run for different durations of time. For each of four consecutive days, the 50 microsprinklers were sequentially turned on every 35 seconds and then all turned off after 30 minutes. Water was collected from 25 microsprinklers, volume was plotted against field position, and linear regression was used to analyze the data (Figure 8). Since the nodes were turned on at regular intervals, water was applied in a linear gradient across the field. Each microsprinkler applied a consistent volume of water from day to day, although slightly more water was applied on day 4 because the system water pressure increased due to other irrigation blocks being shut off. Also, the data exhibited a slight curve, caused by a 15 kPa higher water pressure in the laterals of the two outer rows. As evident from the day 4 measurements and data curvature, changes in water pressure adversely affected microsprinkler discharge uniformity. Nevertheless, time-control demonstrated that the spatially variable system worked on the individual microsprinkler level and performed consistently over multiple days.

Figure 8. Water volume vs. microsprinkler position over four days, with the time of actuation a linear function of microsprinkler number.

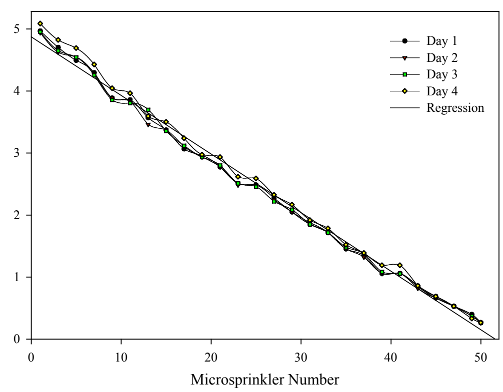
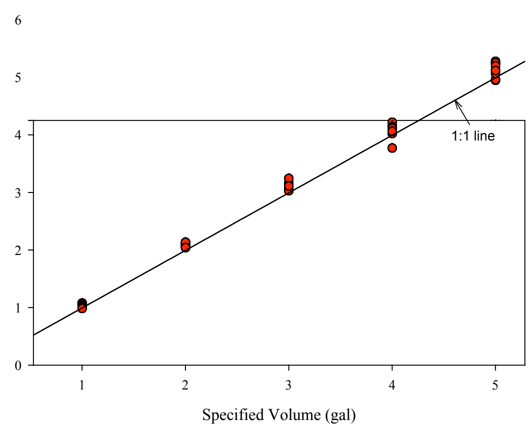


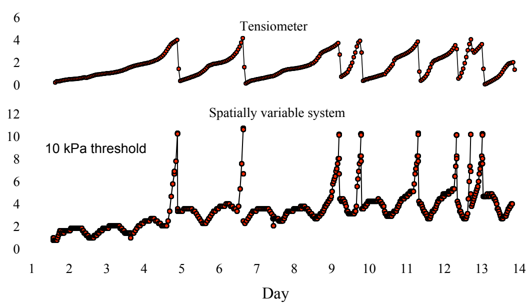

Figure 9. The actual volume of water collected during the volume-controlled test vs. the volume of water specified in the schedule.




Volume-controlled irrigation was created to address the fundamental problem with time-controlled spatially variable irrigation: water pressure in each lateral changed depending on how many microsprinklers were running at a given time, causing flow rates to vary. To remedy this problem, pressure sensors were installed at each row and individual microsprinkler run-times were adjusted as pressure changed. Microsprinklers were scheduled to apply 1, 2, 3, 4, or 5 gallons of water. The water volume specified in the schedule was compared to the actual volume collected from each microsprinkler during the test (Figure 9). Laterals along the two inner rows consistently operated 14 kPa lower than the outer laterals, so the drip line controller calculated longer irrigation run-times for microsprinklers along the inner laterals, as expected. The microsprinklers discharged an average of 3.7% more water than specified, and the average coefficient of variation for the actual volumes at each specified volume was 2.5%, indicating that there was good application rate uniformity. Differences between actual and specified volume could have been due to flow calibration inaccuracy, emitter manufacturing variability, or partial clogging of the valves and emitters. In spite of these differences, volume-controlled irrigation was an important strategy to overcome the effects of pressure variation by allowing more accurate control of water, and eventually fertilizer, using feedback from sensors in the field.

Since soil moisture sensors are sometimes used for irrigation control, they were implemented in the spatially variable microsprinkler system. The field could be divided into any number of irrigation zones, each monitored by one or more sensors. When a zone required irrigation, all microsprinklers assigned to that zone would be turned on. A greenhouse test was conducted to evaluate the soil-moisture-control strategy. Two small potted plants were each irrigated by two nodes with 1 gph drip emitters. A soil moisture sensor was connected to one node in each pot. Pots 1 and 2 were considered to be in separate irrigation zones with soil tension thresholds of 10 and 15 cb. When the soil of a plant became too dry, both of its drip emitters were turned on. Once the soil was sufficiently wetted to fall below the threshold, the emitters were turned off. Soil water tension was also measured every hour with tensiometers and recorded with a datalogger. Readings from the soil moisture sensor and tensiometer in both pots were plotted over time and the results for pot 1 are shown in Figure 10. The saturated soil took about three days to dry before the first watering. Moisture readings fluctuated due to daily changes in sensor temperature, although temperature compensation could have prevented this. The emitters in pot 1 turned on eight times and the emitters in pot 2 turned on eleven times during the 13-day test. The nodes always turned on at the specified thresholds (10 and 15 cb) and then ran for approximately two minutes. This drove the actual soil water tension far below the thresholds because excess water was applied before it could percolate into the soil and saturate the sensors. The sensor measurements were more than double the values from the tensiometer due to calibration equation inaccuracies and inherent problems with the granular matrix sensors. In spite of these measurement problems, the system correctly responded to the readings, showing that spatially variable control using soil moisture sensors is feasible. The ability to group individual microsprinklers in any size or shape irrigation zone is important because it provides more flexibility in system design than other soil-moisture controlled systems.

**Figure 10. Soil water tension in pot 1 (10 cb threshold) over 14 days, with the upper curve showing tensiometer readings and the lower curve showing soil moisture sensor data.**




***Automated Fault Diagnosis***

Row-level and node-level fault diagnosis routines were developed to detect emitter clogging and damage. Pressure transducers were located at the inlet of each lateral in the prototype system (4 rows). The node condition was classified as clogged, normal, or damaged based on pressure change features during valve cycling. Damaged nodes were simulated by removing the emitters from the distribution tubes. Clogged emitters were simulated by stuffing cellophane into the distribution tubes and replacing the emitter.

In row-level diagnosis, a microsprinkler was tested by measuring pressure changes at the inlet of the drip line along which it was located. Pressure readings were transmitted to the drip line controller and used to classify the node. Twenty pressure readings each were taken before opening the valve, after opening the valve, and after closing the valve. Nodes were classified based on the changes in average pressure after opening and closing the valve. Tests were then conducted on all 50 microsprinklers under each of the three conditions. Of the 150 total row-level fault diagnosis attempts, 146 were correct, giving a 3% overall error rate (Table 1). Three damaged nodes were incorrectly classified as normal and one normal node was incorrectly classified as damaged. It is possible that partial valve clogging caused the incorrect classifications. The results suggested that the difference between normal and damaged microsprinklers was not easily distinguished using row-level diagnosis.

**Table 1. Row-level fault diagnosis results with error rates**

| Actual Condition | Predicted Condition Damage | Normal | Clog | Total | Error (%) |
|---|---|---|---|---|---|
| Damage | 47 | 3 | 0 | 50 | 6 |
| Normal | 1 | 49 | 0 | 50 | 2 |
| Clog | 0 | 0 | 50 | 50 | 0 |
| Total | 48 | 52 | 50 | 150 | 3 |

While row-level tests required only one sensor per row, node-level tests were predicated on the assumption of a pressure sensor at every microsprinkler node in the field. Classification was done by the node itself, and the final result was transmitted to the drip line controller. Forty pressure measurements were taken after opening the valve and another 40 after closing the valve. Nodes were classified based on the magnitude of the water pressure fluctuations induced by valve cycling. Four microsprinkler nodes had a pressure sensor connected to the drip line near the valve. Each was diagnosed 18 times under the three conditions. Of the 216 total node-level fault diagnosis attempts, 213 were correct, giving a 1% overall error rate (Table 2). One clogged node was incorrectly classified as normal, one damaged node was incorrectly classified as normal, and one normal node was incorrectly classified as clogged. Further refinement of these routines could reduce the rate of incorrect diagnoses. It is clear that automated fault detection is possible and could be a valuable tool in irrigation system management by reducing water and fertilizer loss through damaged microsprinklers, reducing tree stress due to clogged emitters, and decreasing time spent troubleshooting the system.

**Table 2. Node-level fault diagnosis results with error rates**

| Actual Condition | Predicted Condition Damage | Normal | Clog | Total | Error (%) |
|---|---|---|---|---|---|
| Damage | 71 | 1 | 0 | 72 | 1 |
| Normal | 0 | 71 | 1 | 72 | 1 |
| Clog | 0 | 1 | 71 | 72 | 1 |
| Total | 71 | 73 | 72 | 216 | 1 |

## Conclusions

A spatially variable irrigation system was developed, consisting of a network of microsprinkler nodes controlled by a drip line controller and master computer. Each node included a simple microcontroller, electrical components to control water flow with a latching solenoid valve, and a microsprinkler. A prototype system with 50 microsprinkler nodes was installed and tested in a nectarine orchard. Evaluation of the system established that precision microirrigation on the individual emitter level is possible and has a number of advantages over conventional systems. Using a time-control strategy, a gradient of water was effectively applied across the orchard. Small changes in water pressure, however, caused variations in flow rate and inaccuracies in water delivery. Volume-control overcame this problem by using sensor feedback to adjust microsprinkler run-time, allowing for more accurate application of water at each node. Soil-moisture-control used sensor feedback to adjust the time and duration of water application based on soil conditions. The distributed intelligence of the microsprinkler nodes and sensors allowed automated detection of clogged and damaged emitters. Automated fault detection could reduce labor costs associated with troubleshooting system performance while reducing water and fertilizer loss from undetected damage.

## Future Research

The disadvantages of using a wired network for power and communication were installation time, loose connectors, risk of damage by machinery, and lightning sensitivity. To help alleviate these problems, self-powered nodes with wireless communication are under development. The volume-controlled irrigation strategy and emitter fault detection routines could be made more effective by using a differential pressure sensor across each valve to determine individual microsprinkler flow rates. Other control strategies could also be explored by using alternative types of sensors to measure tree water demand and monitor system status.

# Seasonal Patterns of Nutrient Uptake and Partitioning as a Function of Crop Load of the 'Hass' Avocado

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## Introduction

For the 'Hass' avocado (*Persea americana* L.) industry of California, optimal rates and times for soil fertilization of nitrogen, phosphorus and potassium have not been adequately determined. Fertilization rates and optimal leaf nutrient ranges have been borrowed from citrus. Competition from Mexico and Chile requires the California avocado industry to increase production per acre to remain profitable. Optimizing fertilization is essential to achieve this goal.

The seasonal pattern of nutrient uptake is a key component of fertilizer management. Matching fertilizer application times and rates with periods of high nutrient demand not only maximizes yield, but also increases nutrient-use efficiency and, thus, reduces the potential for groundwater pollution. Experiments on nutrient uptake and allocation are routinely done to develop best management practices for commercial annual crops. However, determining nutrient uptake in mature trees is considerably more difficult, requiring repeated tree excavations at important phenological periods over the season. Thus, few best management practices have been developed for perennial tree crops.

The goal of this project is to determine the seasonal pattern of nutrient uptake and partitioning in alternate-bearing 'Hass' avocado trees. The research will quantify the amount of each nutrient partitioned into vegetative or reproductive growth and storage pools. The research will identify the periods of high nutrient use from bloom to harvest as a function of crop load, and thus identify the amount of each nutrient required, and when it is required, to produce an on-crop and good return crop the following year. The results will enable us to provide guidelines for fertilization based on maximum nutrient-use efficiency and eliminate applications made during ineffective periods of uptake to thus protect the groundwater and increase profitability for California's 6,000 avocado growers.

## Project Objectives

1 To quantify the seasonal pattern of N, P, K, B, Ca, and Zn uptake and partitioning in bearing 'Hass' avocado trees;
2. To quantify the effects of different crop loads on these seasonal patterns of nutrient uptake, partitioning into vegetative and reproductive growth, and storage;

3. To determine the seasonal patterns of nutrient uptake in alternate bearing avocado trees and to develop best management fertilizer practices for the 'Hass' avocado tree.

## Project Description

The research was conducted in a commercially bearing avocado orchard in Somis, CA. In June 2001, 60 trees were selected for inclusion in the project based on their trunk diameter, height, canopy size, and fruiting potential. Thirty of these trees were subsequently defruited to establish both lightly fruiting and heavy fruiting trees. The experiment was set up as a completely randomized design, with factors: 1) cropping status (heavily cropping—On and lightly cropping—Off trees) and 2) time of excavation. Two trees (an on- and an off-year tree) were excavated monthly between November 2001 and December 2002 for a total of 13 excavation dates. The entire tree (roots and shoots) was excavated every third month (4 dates), and the aboveground dry matter was harvested for the other nine dates. Trees were dissected into the following components, and the total weight of each component determined: leaves, new shoots, inflorescences or fruit (separated into seed and flesh), small branches (£ 2.5 cm), mid-size branches (2.5-5.0 cm) scaffolding branches, scion trunk, rootstock trunk, scaffolding roots, small roots, and new roots. Sub-samples were dried, ground, and analyzed for carbon, nitrogen, nitrate-nitrogen, phosphorus, potassium, calcium, iron, magnesium, manganese, zinc, boron, sulfur, copper, sodium, chloride, and aluminum.

Ten percent $^{15}N$ enriched ammonium sulfate was applied on three dates (August, 15, 2002; November 14, 2002; June 15, 2003) and whole trees were excavated three months after application and analyzed for percent $^{15}N$ recovery. $^{15}N$ analyses from the June 15 tree excavation are currently being conducted and these data will be reported at a later time. These data will be used to determine periods of high N uptake capacity in avocado trees and evaluate the effects of alternate bearing on N uptake and recovery. Such data are required to develop best management N fertilizer practices.

***Data analysis.***
The results obtained were used to calculate gram nutrient per tree by the following equation using nitrogen as the example:

g N/g dry wt tissue X g dry wt tissue/g fr wt tissue X total fr wt tissue/tree = total g N/tree

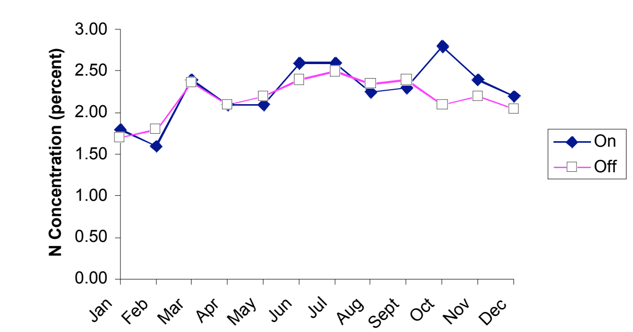
Nutrient uptake was determined as the difference in total tree nutrient contents from sequential tree excavations and from $^{15}N$ recovery in the various tree parts.

## Results

*Quantify seasonal pattern of nutrient uptake and partitioning as a function crop load of the 'Hass' avocado.*

***Leaf N Concentrations***
Alternate bearing had little effect on the changes in leaf N concentrations over the season (Figure 1). Leaf N concentrations tended to increase over the season, however, few differences were seen between on- and off year trees. This is surprising since avocado trees accumulated significant quantities of nitrogen in their fruit and this demand was not reflected in lower leaf N concentrations. In other alternate bearing species such as pistachios, leaf N concentrations are frequently lower in on- vs. off-year trees. This indicated that avocado leaves are highly buffered against large N demands by the fruit.

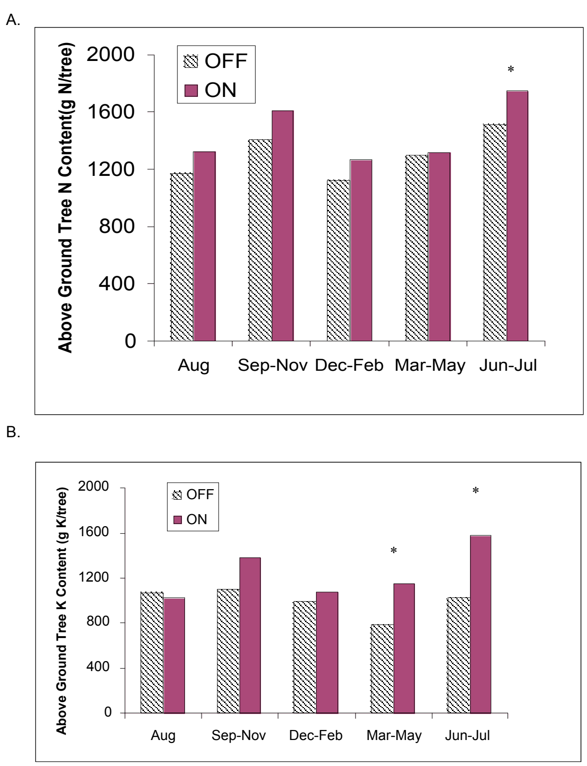
**Figure 1. Effect of alternate bearing on leaf N concentration over the 2002 season.**




***Total Aboveground Tree N and K Accumulation***
Total aboveground tree N and K contents were averaged over a three-month period in the late summer (September-November), winter (December-February), and spring (March-May), and averaged over a two-month period during fruit growth and maturation (June-July) for both on- and off-year trees (Figure 2). Tree N contents increased by almost 50% in both on- and off-year trees between the

spring and fall. Increases in leaf and fruit nitrogen (in on-year trees only) pools over the season were the primary factors in producing these increases in tree N status (data not shown). In the fall, heavy fruit loads resulted in on-year trees containing significantly more N than off-year trees. Potassium levels increased significantly in on- vs. off-year trees during fruit growth and maturation. On-year trees contained almost 60% more K than off-year trees at fruit maturity in June and July.

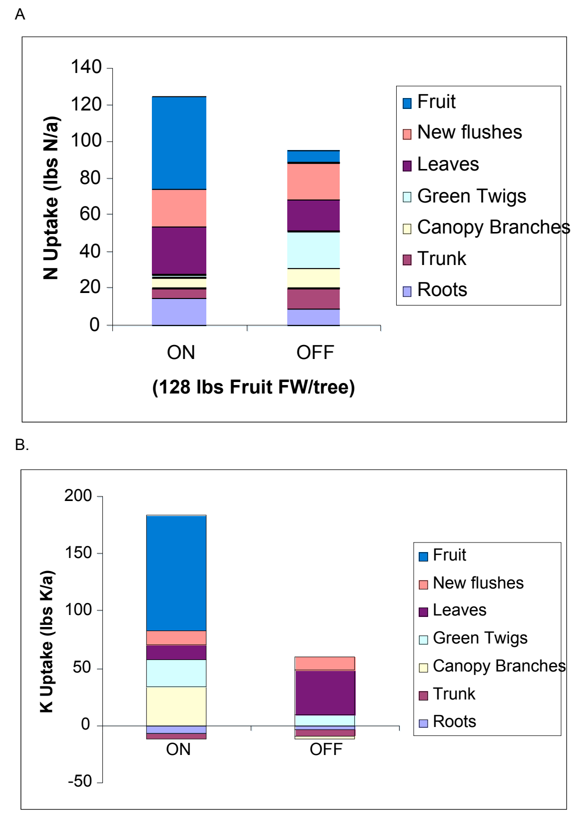
**Figure 2. Aboveground tree dry nitrogen (A) and potassium contents (B) of mature avocado trees over the season. * indicate significance between on- and off-year trees at p =0.05.**




### *Tree N and K Uptake Over the Alternate Bearing Cycle*

An estimate of total tree N and K uptake was determined by the difference in tree nutrient content at bloom (February) and at fruit harvest (the following July) in both on- and off-year trees (Figure 3). Over the alternate bearing cycle, on-year trees took up 125 lbs of N and 171 lbs of K per acre, and fruits comprised 40% and 59% of the total N and K uptake, respectively. In contrast, only 95 lbs of N and 48 lbs of K per acre were taken up in off-year trees. Almost 80% of K in the tree was located in the leaves during the off year.

**Figure 3. Uptake of N (A) and K (B) (lbs/a) in various tree components over the alternate bearing cycle in mature 'Hass' avocado trees.**




*Quantify seasonal pattern of nitrogen uptake and partitioning using labeled nitrogen fertilizer ($^{15}N$ ).*

Ten percent $^{15}N$ enriched ammonium sulfate was applied on two dates (August, 15, 2002 and November 14, 2002) and whole trees were excavated three months after application and analyzed for percent $^{15}N$ recovery. Percent $^{15}N$ recoveries in November were 59 and 35% for the on- and off-year tree, respectively. The on-year tree recovered almost double the amount of $^{15}N$ as the off-year tree (data not shown). Most of the $^{15}N$ recovery in the on-year tree accumulated in the fruit, whereas leaves were the main repositories for 15N in the off-year tree (Figure 3). In both the on- and off-year tree, the majority of the $^{15}N$ was translocated out of roots and accumulated in actively growing tissues such as fruit, leaves, and green twigs (Figure 3). These results support the hypothesis that N uptake is regulated by tree N demand.

On-year trees have a large N requirement and, therefore, more is taken up to meet that demand.

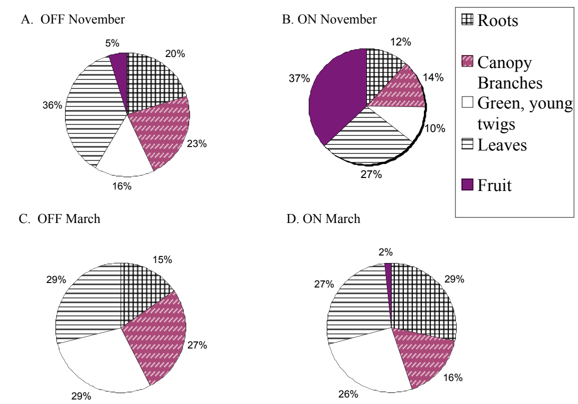
These recovery percentages in both on- and off-year avocado trees are high compared to the typical 15-30% $^{15}N$ recovery rates reported in the deciduous fruit crop literature. This indicates that August fertilizer N applications are efficiently taken up by roots and mobilized by the tree. Avocado trees have very dense root mats, which may have contributed to the high $^{15}N$ recovery rates.

The percent recovery rates of $^{15}N$ applied to trees in November and excavated in March were 11 and 27% for on- and off-year trees, respectively. Thus, the off-year tree recovered more than twice as much $^{15}N$ as the on-year tree when applied in November.

The $^{15}N$ accumulated equally between leaves, green twigs, and canopy branches in the off-year tree (Figure 3). In contrast, the roots accumulated the most $^{15}N$ in the on-year tree. This lack of $^{15}N$ translocation out of roots may reflect the lower N requirement for on-year trees at this time. These $^{15}N$ recovery results appear to contradict earlier reports that N uptake, translocation and allocation are a function of sink demand. Not so, on-year trees in November would have fewer new vegetative shoots to support than off-year trees, and since they were going into an off-year bloom in Spring 2003, they would also have fewer reproductive sinks. Fruit accumulated only two percent of the total $^{15}N$ recovered. In March, inflorescences were just pushing out and weighed only 1.8 kg fresh weight per tree. Growth of mature avocado fruit was just beginning to resume again in March as air and soil temperatures increased. Thus, fruit demand for N was low at this time. In contrast, trees carrying an off-year crop would have produced more vegetative shoots during the previous months and would be supporting the development of inflorescences for an on-year bloom in March 2003.

The $^{15}N$ recovery rates were markedly lower when applied in November compared to August. The cold and wet weather likely contributed to these lower recovery rates in two ways: 1) high rainfall events likely increased nitrogen leaching, and 2) cold weather decreased tree growth which concomitantly reduced tree N demand.

**Figure 4. $^{15}N$ distribution in mature off- (A) and on-year (B) avocado trees, applied August, 15, 2002 and excavated on November 14, 2002, and $^{15}N$ distribution in off-(C) and on-year (D) trees applied November 14, 2002, and $^{15}N$ distribution in off-(C) and on-year (D) trees applied November 14, 2002, and excavated on March 15, 2003.**




## Conclusions

An understanding of seasonal tree nutrient requirements is critical in developing best-management fertilizer practices. By excavating whole trees, determining N, P, and K uptake, and analyzing for $^{15}N$ recovery, we have established nutrient uptake patterns over the season in on- and off-year avocado trees. Nutrient applications should be coincident with these periods of high tree demand. Careful analysis of tree growth patterns (particularly of fruits and leaves) can indicate when tree nutrient demand is high and, thus, when nutrients should be applied to maximize tree nutrient uptake and reduce environmental pollution. Nutrient leaching losses should be minimized by coordinating fertilizer applications with periods of high plant demand.

# IMPROVING THE PROCEDURE FOR NUTRIENT SAMPLING IN STONE FRUIT TREES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## INTRODUCTION

This project was initiated to investigate the possibilities of using a dormant sampling technique to complement the widely used mid-summer leaf sampling for nutrient analysis. The argument was made that this approach might fit better into a grower's typical fertility management program and be more timely for correcting most deficiencies. We have now collected three years data on 60 Zee Lady peach and 60 Grand Pearl nectarine trees growing in sand culture. By varying fertilization rates we have been able to obtain a wide range of nutrient levels among the trees and have observed distinct deficiency symptoms for several nutrients. Each year we collected dormant shoot samples from the trees in January and analyzed them for 12 essential elements. Based on tree performance and deficiency symptoms we have established thresholds for some nutrients that have stayed consistent over all three years for both the peach and the nectarine. During 2005, our emphasis was on testing these thresholds in commercial peach and nectarine orchards in the San Joaquin Valley. We surveyed about 90 different orchards and applied fertilizer treatments to those that tested low for a given nutrient.

## OBJECTIVES

1. To test the feasibility of measuring boron, zinc, and nitrogen (and other nutrients if possible) in stone fruit trees during the dormant season or early spring and relate those nutrient levels to the various components of yield and fruit quality.
2. To develop deficiency threshold values for these nutrients that can be used to guide fertilization decisions early in the season.
3. To test the usefulness of these threshold values in commercial orchards.

## PROJECT DESCRIPTION

Sixty large plastic tanks measuring 11'x 8' and 4' deep were obtained in 1999 and placed in trenches in the field. In 2000, each tank was filled with sand and planted with a Zee Lady peach, Grand Pearl nectarine (white flesh) and Fortune plum tree. Fifteen different fertilizer treatments have been imposed since 2001 (see 2000 through 2003 FREP reports for details). The main objective was to obtain trees deficient in each essential nutrient. By 2005, there were clear signs of N, P, B and Zn deficiencies in multiple peach, plum and nectarine trees. There were also individual trees exhibiting K and Mn deficiency symptoms and other trees showing indications of other deficiencies as well.

Shoot samples were taken from all 180 trees in January of 2003, 2004 and 2005 and analyzed for N, P, K, S, Ca, Mg, B, Zn, Mn, Fe, Cu, and Mo. Measurements were made of yield and fruit quality components including flowering, fruit set, early fruit growth, early shoot growth, fruit drop, final fruit size, fruit defects, fruit quality, and total vegetative growth. These parameters were then correlated with nutrient levels in the dormant shoots. Using this approach, deficiency thresholds were proposed for N, P, B, and Zn (see 2004 FREP report). Data from 2005 supported these thresholds (Table 1).

**Table 1. Proposed deficiency thresholds of N, P, B and Zn in dormant shoots of peaches and nectarines.**

| Nutrient | Proposed Deficiency Thresholds |
|---|---|
| Nitrogen | 1.2% |
| Phosphorus | 0.12% |
| Boron | 14 ppm |
| Zinc | 20 ppm |

The emphasis in 2005 was on applying these deficiency thresholds to commercial orchards. During July 2004, 60 peach and nectarine orchards were sampled using the standard mid-summer leaf sampling technique. Many of these orchards were on sandy soils or in areas where B deficiency had been diagnosed in nearby grape vineyards. Those testing low for any nutrient (18 sites) plus an additional 29 orchards were then sampled in January using our experimental dormant shoot sampling technique. Fertilizer treatments were then applied to those orchards with nutrient levels below or near the thresholds established from the sand tank trees.

## RESULTS

The commercial orchard survey showed nutrient ranges similar to those found in the sand tank trees. Many of the nutrients did not appear to be deficient in any of the orchards tested. Only those showing some promising results will be discussed below.

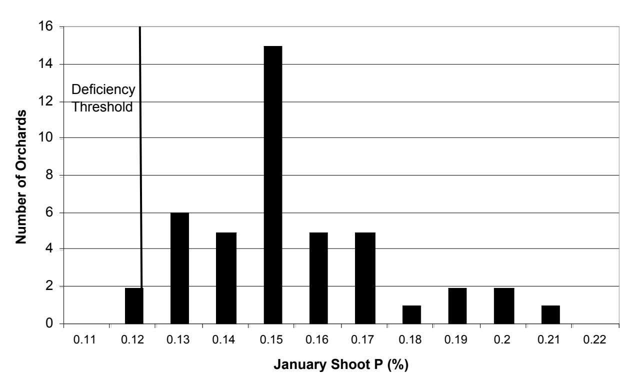
### *Nitrogen (N)*

N in dormant shoots ranged from 0.98 to 1.77% in the orchard survey, very similar to values found in the sand tank trees. Even though we set a deficiency threshold of 1.20%, we don't have a lot of confidence in this value. Many of the trees below or close to the threshold were vigorous and exhibited no symptoms of N deficiency. Likewise, the trees in the sand tanks showed the same sort of variability. In this case, trees that were clearly nitrogen deficient often had dormant shoot values greater than 1.20%. Rather than measuring total N in shoots, we will pursue another test for N that has shown promise in the scientific literature. Specific amino acids such as arginine have been shown to be very indicative of the N status of fruit trees. Arginine is the main storage amino acid in dormant peach trees. Therefore, we will test the strength of the correlation of this amino acid with vegetative growth and nitrogen deficiency symptoms.

### *Phosphorus (P)*

In the orchard survey of dormant shoots, P values ranged from 0.12 to 0.21% (Figure 1). The sand tank trees that were very deficient had P values as low as 0.06%. Thus, the survey did not reveal any truly deficient trees. Two of the orchards tested 0.12% P, which is right at the threshold value we established from the sand tank trees. Phosphorus fertilizer was added to individual trees within these two orchards plus a third that tested 0.13%. During 2005 none of these orchards exhibited symptoms of P deficiency such as low vigor, cracked fruit or early defoliation. In 2006, we will continue to monitor the trees to see if additional P has any effect on productivity or fruit quality.

**Figure 1. The distribution of dormant shoot P levels in a survey of 44 commercial peach and nectarine orchards in the San Joaquin Valley.**



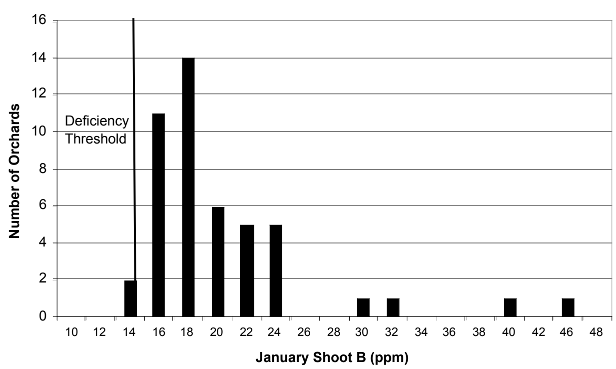
***Boron (B)***

B in dormant shoots ranged from 13 to 45 ppm in the orchard survey (Figure 2). These values are considerably greater than those measured in the sand tank trees over the past three years. Typically, the trees showing signs of B deficiency in the sand tanks ranged from 8 to 12 ppm, although we set the threshold at 14 ppm. Therefore, the two orchards that tested 13 ppm in the orchard survey could theoretically benefit from boron fertilization. We applied foliar B at bloom to individual trees in both these orchards but saw no improvement in fruit set or fruit size in 2005. We will continue to monitor the orchards through 2006.

***Zinc (Zn)***

In the spring of 2003, 2004 and 2005, we observed a range of Zn deficiency symptoms in the sand tank trees that correlated well with dormant shoot Zn levels. However, there have always been some trees with very low Zn levels that showed no symptoms and grew vigorously. Likewise, in the orchard survey there were several sites that tested low in Zn but showed no symptoms. This has prompted us to ask a series of questions about zinc and led to a second FREP project. Hopefully these questions, as well as several more related to increasing zinc uptake efficiency, will be answered by this project (see our other report in this issue).

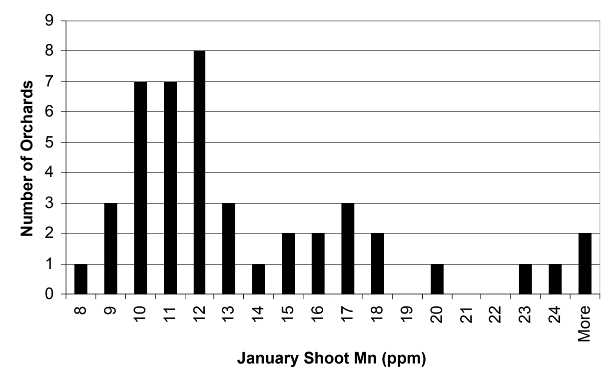
**Figure 2. The distribution of dormant shoot B levels in a survey of 47 commercial peach and nectarine orchards in the San Joaquin Valley.**




***Manganese (Mn)***

Some interesting results regarding Mn were obtained in 2005. In the sand tank trees we have been unable to achieve Mn deficiency other than one plum tree with very minor symptoms. However, in the survey, four orchards tested as low as 8 or 9 ppm in the dormant shoots (Figure 3). Three of these four orchards, as well as several at 10 ppm, all showed early spring symptoms that looked similar to published reports of Mn deficiency. Therefore, we applied Mn fertilizers (both foliar and soil applied) to individual trees in two of these locations. Whether trees were fertilized or not, the symptoms generally disappeared and the trees grew vigorously once hot weather arrived. Therefore, it is still uncertain whether this disorder causes any problems with productivity. In 2006 we will make observations of both spring symptoms and productivity indicators.

**Figure 3. The distribution of dormant shoot Mn levels in a survey of 44 commercial peach and nectarine orchards in the San Joaquin Valley.**




***Potassium (K), Magnesium (Mg) and Calcium (Ca)***

We have not observed K, Mg or Ca deficiency in the sand tanks except for one peach tree that showed K deficiency symptoms late in 2005. One of the problems has been fairly hard water that is our main source for irrigation. To help us achieve deficiencies of these cations, we will install a water softening system in 2006 to remove Mg and Ca from the irrigation water. We will also install a 5,000-gallon tank and use it to irrigate a few of the sand tanks with deionized water.

## CONCLUSION

Although we have been able to induce nutrient deficiencies with mature peach and nectarine trees in sand culture, it has been difficult to find them in commercial orchards in the field. The use of dormant shoots to test for deficiencies of P, B and Zn still seems reliable even though we have not been able to test the procedure fully in commercial orchards. The procedure for N deficiency needs to be refined and hopefully other nutrient thresholds can be added as we induce more deficiencies in the sand tank trees. In 2006, we will also survey commercial almond orchards to see if we find the same range of nutrients and if the same deficiency thresholds can be used.

# Planning Application Rates for Organic Fertilizers

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## INTRODUCTION

As a general rule, organic fertilizers should be managed differently than conventional fertilizers. Nitrogen (N) bound up in organic forms only becomes plant available as it is released by microbial activity in the soil, a process called mineralization. The factors that determine the rate at which mineralization occurs include the chemistry of the fertilizer as well as soil conditions such as texture and moisture, but the most important factor for an irrigated soil is temperature. Microbial activity rapidly accelerates as temperatures increase so that for every 18°F increase in soil temperature the nitrogen mineralization rate roughly doubles. Because temperature is so important, a given fertilizer will behave differently when applied in different locations or from one season to the next.

Nutrient budgets that incorporate organic fertilizers should match fertilizer mineralization rates as closely as possible to the evolving N needs of the crop system. For certified organic farmers, this reduces the amount of fertilizer that must be purchased and applied. It also minimizes nitrate leaching potential, a concern for all operations and most particularly animal agricultural operations where beneficial manure disposal options are a critical need.

## OBJECTIVES

1. To represent the uptake of nutrients by a developing crop system.
2. To represent the release of nutrients where temperatures are changing over time.
3. To schedule application rates of organic fertilizers so that crop needs are met while minimizing nitrogen losses to the environment.

## DESCRIPTION

***Crop N Uptake***

The hypothetical system under consideration is typical of Stanislaus County dairy operations mixing lagoon and irrigation water to supply nutrients to forage crops, in this case silage maize and winter triticale. To represent crop N demand over time, we used an "S" shaped mathematical equation based upon five parameters. Three of the parameters determine the shape of the curve for a particular crop. Because expected yields differ from different fields, the shape is customized for a particular operation with two additional values, representing the harvest time in growing-degree days (GDD) and the nutrient removal expected with the harvest (lb N/acre). The equation uses local GDD rather than ordinary time to include the effects of climate on crop development. Parameter values for maize were taken from the literature because corn development has already been extensively studied. To develop parameters for winter grains, we collected replicated samples throughout the growing season from some 48 plantings between 1997 and 2002 including various strains of wheat, triticale, rye, and oats. Of these, 37 were harvested once and 11 were harvested twice. Although these crops develop differently, we found that one equation adequately described all grain crops when adjusted for local conditions using harvest time and yield N information along with local GDD data - as long as grains were collected in a single harvest operation (Figure 1). Crops harvested twice required a slightly different parameterization.

**Fig. 1. Observed and model N uptake for selected experiments. Grains include T2700 triticale (T), Dirkwin wheat (DW), Cayuse oats (CO), Swan oats (SO), and Longhorn wheat (LW). Lines represent the model while points represent actual measurements. The T2700 triticale and Dirkwin wheat model lines are superimposed.**

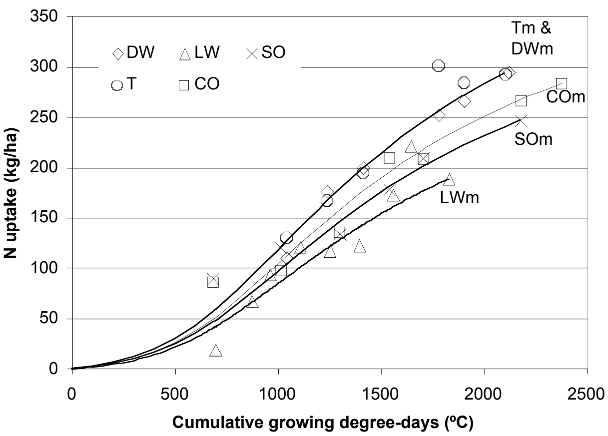
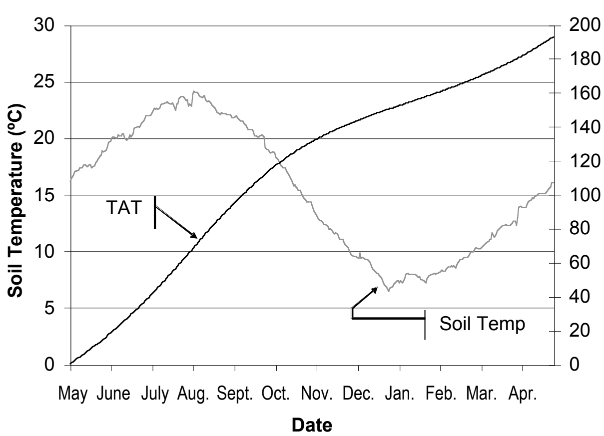



**Fig. 2. Mean daily soil temperatures (15 cm) and cumulative temperature-adjusted time (TAT) for Modesto, CA.**




***N Release***

Organic fertilizers typically contain an inorganic fraction along with the organic N content. The inorganic N is considered to be immediately plant available, while an exponential decay function is used to represent mineralization of the organic fraction. We used an approach similar to GDD to include the effects of soil temperatures on mineralization. A biochemical relationship known as the Arrhenius equation was used to modify time so that time during the summer was effectively stretched, allowing for more mineralization, while time during the cool winter was compressed (Figure 2). Reference mineralization rates were derived from the literature. Seasonal effects on soil temperatures were included by modeling mineralization using this temperature-adjusted time (TAT) rather than standard time.

## SCHEDULING

Our approach allows the farmer to choose application days based on farm-specific logistical concerns such as equipment availability, field conditions, or irrigation schedules. Linear programming is then used to determine optimal application rates for each potential application date. Linear programming is a relatively simple optimization approach built into many software packages, including Microsoft Excel. The model minimizes the amount of fertilizer N that is applied in a given year subject to the constraint that the crop receives all of the N it needs throughout the growing season.

The approach also assumes that the system is operating under a steady-state condition. This does not mean that soil nitrogen conditions are not changing. Conditions change continuously as fertilizer is applied and organic N mineralizes to plant-available N (PAN) forms. When organic fertilizers are added in a similar manner from year-to-year, however, soil conditions converge to a consistent pattern. Steady state occurs when conditions at a particular date, such as June 1, are similar from year-to-year. This can occur relatively quickly when fertilizers are relatively available. For example, a fertilizer with a half-life of 250 days would fall within 95 percent of steady state within three years and within 98 percent within four years. (For mathematical reasons, complete steady state is never actually reached; rather it is approached.)For the purposes of this example, the year was broken into ten-day planning periods. Lagoon water can be applied at the beginning of any planning period to meet the needs of a maize-triticale rotation. Nitrogen remaining at the end of a planning period is considered to be leach. This is a realistic assumption in the highly permeable flood-irrigated fields in the study area. Denitrification losses are not considered in this example, since denitrification is not considered to be an important process in the area of study, but it can be considered where it is predictable.

One version of our approach assumes that mineralization rates are completely known, while another incorporates uncertainty with respect to both reference mineralization rates and the influence heat exerts upon mineralization. All manures were considered to be 50% inorganic N (ammonium) and 50% organic N.

## RESULTS

Applications applied at just the crop's need of 504 kg/ha/yr would result in annual deficits of 111 kg/ha. This occurs because added organic N is not immediately available. Losses occur when mineralization delivers N at times of low demand. Figure 3 shows the predicted result when manures are applied at a rate equal to the crop N demand plus 30% (+30%) to the optimized rate. Shaded areas represent leaching losses and crop deficits. This can be compared to the optimized result (Figure 4). Optimization eliminates crop deficits and decreases leaching N from 188 to 104 kg/ha/yr (Table 1). Under the optimized application plan, fertilizer is applied earlier in the spring than in the +30% plan (Figure 5). Winter applications are greater since mineralization rates are slower during the cool winter months.

**Fig. 3. Total crop N demand, manure inorganic N, and manure-derived plant-available N (PAN) during 10-day planning periods when total fertilizer N is applied at 30% above crop needs (+30%). PAN is the manure inorganic N + mineralized N. Shaded areas represent potential crop N deficits and surplus N.**

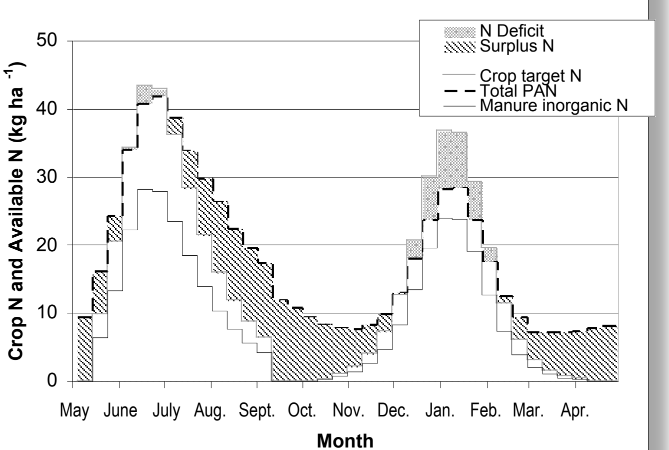



**Table 1. Optimization results.**

| Plan | Applied N (kg ha-¹ yr-¹) | Soil Excess N (kg ha-¹ yr-¹) | Crop Deficit N (kg ha-¹ yr-¹) |
|---|---|---|---|
| Crop Demand | 503.9 | 111.0 | 111.0 |
| +30% | 655.1 | 188.2 | 37.0 |
| Optimized | 608.1 | 104.2 | 0.0 |

**Fig. 4. Total crop N demand, manure inorganic N, and manure-derived plant-available N (PAN) during 10-day planning periods for an optimized application schedule. Shaded areas represent potential crop N deficits and surplus N.**

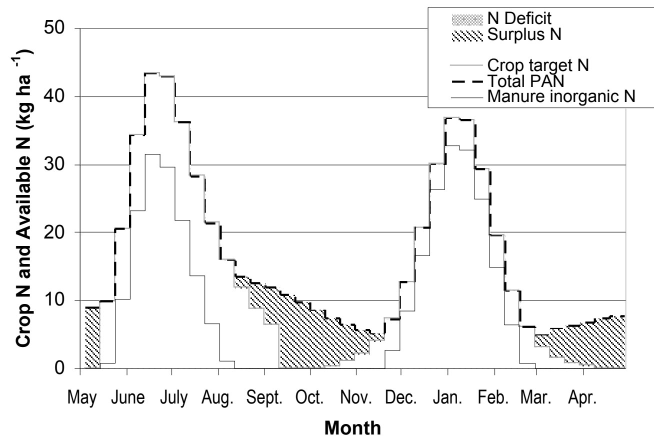
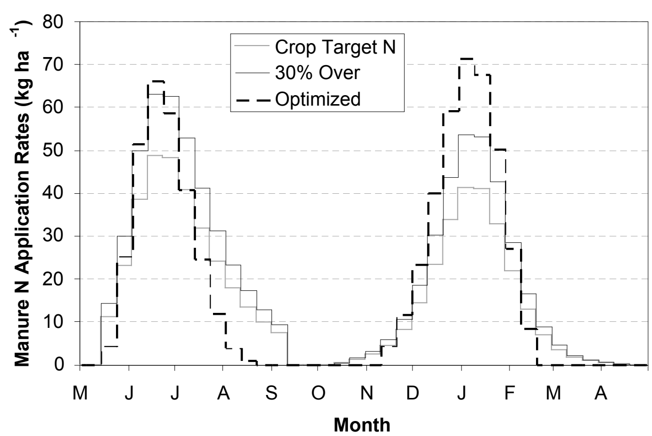



**Fig. 5. Application schedules associated with applications 30% above crop N demand (+30%) and after optimization.**




## RELATED AND FUTURE WORK

This project was programmed in Microsoft Excel. We would like to make it more accessible by developing a more user-friendly interface. Nitrogen uptake curves for various crops are surprisingly limited, but data available in the literature are being developed into usable forms. Finally, there is a need for more information about mineralization of various organic fertilizers under field conditions so that parameters may be developed for this and similar models. In the interim, we are using uncertainty analysis to incorporate environmental variability into our planning model.

# Ammonia Emissions and Fertilizer Applications in California's Central Valley

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## Ammonia Emissions Estimates for Various Fertilizer Applications

Ammonia is the dominant gaseous base in the atmosphere and a principal neutralizing agent for atmospheric acids. The $NH_3$ in the atmosphere, along with alkaline soil dust, may control the acidity of precipitation. Volatilized $NH_3$ may react to form ammonium nitrate or ammonium sulfate and thereby contribute to airborne particulate matter (PM). National standards in the United States for PM apply to the mass concentrations of particles with aerodynamic diameters less than 2.5 microns ($PM_{2.5}$) and less than 10 microns ($PM_{10}$). Estimated patterns of nitrogen deposition suggest that, for California locations close to photochemical smog source areas, concentrations of oxidized forms of N dominate, while in areas near agricultural activities the importance of reduced N forms may increase significantly according to Bytnerowicz and Fenn (1996).

$NH_3$ remains one of the most poorly characterized atmospheric trace compounds in terms of overall sources. This situation persists as a result of several factors, such as experimental difficulties associated with $NH_3$ measurements, rapid gas-to-particle conversion of $NH_3$ in the atmosphere, the capacity of soils, organic matter, vegetation to act as both sources and sinks for atmospheric $NH_3$, and variability in nitrogen fertilizer management and related $NH_3$ emissions (Langford et al., 1992). Consequently, there is a limited amount of published information from which to develop direct emissions estimates of $NH_3$ for the state of California in general, and the state's Central Valley in particular. Preliminary measurements of $NH_3$ background concentrations in the San Joaquin Valley by Fitz et al. (1997) estimated February levels of 3-16 µg m-3 near alfalfa fields. The magnitude and distribution (both regionally and seasonally) of current $NH_3$ emissions from fertilizer and other agricultural sources is still largely undetermined for the state of California and many other large regions where agriculture is a major land use (Matthews, 1994).

The objectives of this study were to measure and characterize rates of ammonia emissions related to applications of N fertilizer followed by an investigation of the variability of atmospheric ammonia as it is affected by climate, time of day, crop type, and other environmental factors. Finally, an attempt to measure the effects of variable rate N applications on ammonia emissions was added to the project in its final year.

The sampling device selected for the project was an active denuder. It represented an established method in air quality studies and it satisfied the inventory development requirement for continuous sampling of emissions over relatively long time periods and large plot areas. The denuder is a medium through which an air stream is passed in a manner similar to a filter for particulates. In the case of $NH_3$ it is a fibrous material, usually glass, treated with a substance (citric acid) that will react with $NH_3$ to form a solid. For this study, a 47 mm disk of glass fiber filter paper was treated with citric acid (5% in 95% ethanol) and dried. A commercially available, 12-volt air sampling pump with a flow regulator was used to pull air through the denuder disk at a rate of about four liters per minute. Airflow was monitored by a rotameter accurate to 0.1 liters/minute and the flow was recorded at the beginning and end of each sampling period. Previous work suggested differences in day and night levels of $NH_3$ in the air, so the sampling was diurnal with the denuders changed at dawn and dusk. Samples were refrigerated and taken to the Graduate Laboratory of the CSU-Fresno, College of Agricultural Science and Technology for analysis. The

$NH_4$-citrate was extracted from the denuder with distilled water and analyzed with a spectrophotometer. The amount of ammonia on the denuder disk was reported in µg $NH_3$. The concentration of $NH_3$ in the air at the sampling point could be determined by dividing the amount of ammonia on the disk by the volume (m3) of air pumped through the denuder in the sampling period to derive the concentration in units of µg N $NH_3$ m-3 air at the sampling point.

The concentration of $NH_3$ at a particular sampling point is not sufficient to determine the emission factor for a particular field site. The amount of $NH_3$ in the atmosphere depends not only on the concentration but also the flow of air at the sampling point. The value necessary to characterize the sampling point was the flux in µg N- $NH_3$ m-2 s-1. The initial assumption during the planning of the project was to monitor ammonia flux at several elevations above the field surface to characterize the gradient between the soil surface and the ambient atmosphere. Denuders and anemometers were co-located at 1, 2, 5, 10 and 18 meters above the soil surface.

Initially, it was assumed that a positive $NH_3$ flux gradient from the soil surface, decreasing as the elevation increased would be found and could be used to determine the magnitude of the emission factor for the sampling period. Prior to the fertilizer application, it was suspected that negative gradients, with higher flux rates in the atmosphere, decreasing at elevations closer to the soil surface, might be found due to ammonia absorption by foliage and/or a moist soil surface. The stomata and internal structure of the leaf that functions to absorb $CO_2$ from the air should also effectively absorb $NH_3$ from the atmosphere near the foliage. Alternatively, the sampling at a site might well exhibit what appears to be a negative gradient, as $NH_3$ in air from nearby point sources (such as livestock or other fertilizer applications) moves over the field and is sampled. The actual results varied somewhat from the initial assumption in that the gradient of $NH_3$ was almost always from the ambient atmosphere to the soil/vegetation surface over the elevation range that was sampled. The magnitude of the $NH_3$ fluxes increased following the fertilizer application but the gradient almost always remained negative.

## Field Sampling Results

Measurement results confirm that field sampling by the micrometeorological mass balance method can detect volatile $NH_3$ from an application of N fertilizer. In each of the applications for which data is available, an increased level of atmospheric $NH_3$ was measured compared to the levels sampled both before and after the application. The expected positive gradient of $NH_3$ fluxes from the surface toward the ambient atmosphere was apparent at only one of the sites, the pasture fertilized with effluent from a dairy shown in Figure 1. The traditional fertilizer applications at the other sites exhibited the increase in $NH_3$ flux that indicated a positive emission factor, but the gradient of the fluxes remained lower at the soil/vegetation surface as shown in Figure 2. The line in Figures 1 and 2 labeled “Application” is the average of 2 to 5 sampling periods during which the N application was actually occurring. The lines labeled “Pre-application” and “Post-application” were the averages of 2 to 10 samples taken prior to and after the application. The “Application” values were greater than those before and after in each of the sites analyzed. This is the basis for the conclusion that the methodology can detect volatile $NH_3$ resulting from a fertilizer application.

**Figure 1. Ammonia flux profiles for dairy lagoon effluent applied to irrigated sheep pasture on the CSU Fresno farm-laboratory June 2000 (site L).**

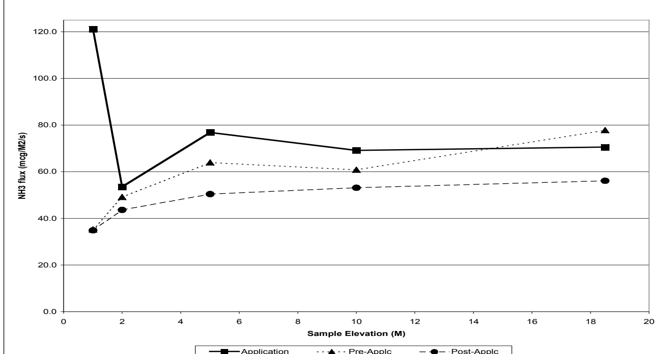
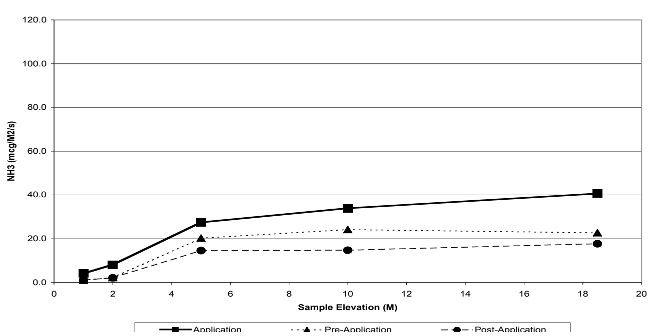


**Figure 2. Ammonia flux profiles for NH4NO3 broadcast on the soil surface of an orange grove near Sanger, California, February 2000 (Site D).**




Standard mass balance micrometeorological techniques (Denmead, 1983) were used to estimate the integrated $NH_3$ flux by combining measurements of wind speed and $NH_3$ air sample concentrations from height-dependent sampling locations mounted on the portable mast.

The surface flux density of a gas can be calculated according to equation 1.

Equation (1) $F = {}_0\int^z U\ (rg - rb)\ \partial z$

where

F = the surface flux density of a gas

U(z) = the horizontal wind speed at sampling height z

rg = the atmospheric gas concentration at the height of the sampler

rb = the background atmospheric gas concentration from upwind of the field plot

Previous field tests (Leuning et al. 1985) suggest that this equation tends to overestimate true fluxes due to turbulent diffusive flow in the opposite (upwind) direction. Therefore, following the recommendation from Denmead, emissions calculated from this equation were reduced by 15%.

To describe the $NH_3$ emission resulting from the fertilizer application, integration calculations were made using a fourth-order polynomial fit to the height-dependent horizontal flux points for each sampling period. Integration under the time series curves and adjustment for fetch distance were made to determine the total N-$NH_3$ emitted as vertical fluxes over the entire time period sampled, beginning at the time of the first fertilizer application. To compute the site emission factor, the total N- $NH_3$ emitted was divided into the total kg N applied m-2 area for that site-sampling period.

**Table 1. Summary of field sampling sites with fertilizer, irrigation and emission factor estimates.**

| SITE | CROP | N lb/Ac | g N m-2 | Fertilizer Type | Irrigation Type | Soil pH | Emission g NH3 m-2 | Emission Factor |
|---|---|---|---|---|---|---|---|---|
| B | Almonds | 100 | 10.9 | C | G | 8.1 | 0.72 | 6.6% |
| D | Citrus | 50 | 5.5 | C | G | 6.1 | 0.24 | 4.3% |
| E | Almonds | 100 | 10.9 | D | M | 6.4 | 0.51 | 4.7% |
| F | Onion | 40 | 4.4 | D | S | 8.4 | 0.28 | 6.5% |
| G | Tomato | 100 | 10.9 | D | G | 7.9 | 0.10 | 0.9% |
| H | Garlic | 50 | 5.5 | D | G | 7.9 | 0.32 | 5.8% |
| I | Cotton | 100 | 10.9 | A | G | 8.5 | 0.62 | 5.6% |
| J | Cotton | 100 | 10.9 | A | G | 7.8 | 0.43 | 3.9% |
| K | Almonds | 9 | 1.0 | A | M | 6.4 | 0.00 | 0.0% |
| L | Pasture | 100 | 10.9 | F | G | 6.6 | 0.32 | 2.9% |
| M | Broccoli | 60 | 6.5 | C | S | 7.9 | 0.10 | 1.6% |
| Q | Lettuce | 40 | 4.4 | D | G | 7.8 | 0.02 | 0.5% |
| R | Tomato | 80 | 8.7 | A | G | 7.9 | 0.01 | 0.1% |
| S | Cotton | 100 | 10.9 | A | G | 8.5 | 0.14 | 1.3% |
| | | | | | | Avg. Emission Factor | | 3.2% |

*Fertilizer Type Codes*
A = anhydrous NH3 or Urea-Ammonium Nitrate below the soil surface at 10-20 cm depth
C = dry Ammonium Nitrate/Sulfate applied to soil followed by irrigation
D = Urea-Ammonium Nitrate (UAN) liquid mixed into irrigation water
F = dairy lagoon effluent mixed in irrigation water

*Irrigation Type Codes*
G = gravity, surface/flood
S = sprinkler
M = microsprayer/drip

Emission flux totals of $NH_3$ for all fertilized sites analyzed, to date, show a notable consistency of emission factor estimates among the different crop types and fertilizer amounts applied as shown in Table 1. While total $NH_3$ nitrogen losses ranged from 0.01 to 0.7 g N- $NH_3$ m-2, the estimated emission factor values for the sites analyzed range from 0.05% to 6.6% with the average at about 3.2%. It appears the sites that produced lower emission factor estimates were primarily those sites where fertilizer was applied in a manner that placed the fertilizer material below the soil surface.

## Statewide Ammonia Emission Estimates from Fertilized Crops

The emission factors estimated from the field data shown in Table 1 were used with correlating data from several sources to build a database for an atmospheric model used at the Ames Research Center - NASA. This database included crop acreage and locations by counties, soil information, and fertilizer application amounts and methods. The crop acreage data was obtained from the California Department of Water Resources. Fertilizer applications were not available from any public source so data was estimated by questioning farmers, fertilizer industry members, county farm advisors and other crop specialists. The practices varied across the state, as expected, but could be correlated with the county-based crop acreage data. The database was used to estimate the application of the various types of N fertilizer to the crops of the state. These estimates were checked by comparing them with the public records of fertilizer sales from the California Department of Food and Agriculture (1999).

The estimated fertilizer applications over the state were then matched with ammonia emission factors from the most similar site monitored during the field study. The soil pH and textural data from the Natural Resources Conservation Service were used along with the rest of the database in a rule-based atmospheric model at the Ames Research Center - NASA to estimate the distribution of ammonia emission across the state from fertilizer applications to agricultural land. The rule-based model was used to assign $NH_3$ emission factors, together with the county level fertilizer application rates to create the statewide inventory estimate for emissions of $NH_3$ directly from fertilizer applications shown in Table 2. The total of these emissions is estimated to be 11.7 x 106 kg N- $NH_3$ annually. The leading counties for annual emissions of $NH_3$ directly from fertilizer sources are Imperial, Fresno, Kern, Tulare, and Kings. Overall, the San Joaquin Valley area accounts for more than one-half of the state's total annual emissions of $NH_3$ directly from fertilizer sources. The Imperial Valley accounts for a higher proportion of the state's total annual emissions of $NH_3$ from fertilizer sources than would be predicted from crop area alone, primarily due to the high proportion of soils with pH above 8 and a major portion of the estimated fertilizer applications to the soil surface.

**Table 2. Estimated $NH^3$-N emission directly from chemical fertilizer application in counties of California.**

| | DWR area total (ha) | $NH^3$-N Emission 106 kg | Avg. $NH^3$ Emission Factor |
|---|---|---|---|
| San Joaquin Valley | | | |
| San Joaquin | 232,531 | 0.66 | 2.41% |
| Stanislaus | 158,549 | 0.40 | 2.38% |
| Madera | 145,660 | 0.27 | 2.30% |
| Merced | 226,158 | 0.65 | 2.64% |
| Fresno | 538,163 | 1.46 | 2.47% |
| Kern | 398,140 | 1.14 | 2.71% |
| Kings | 236,465 | 0.74 | 3.06% |
| Tulare | 307,772 | 0.78 | 2.35% |
| TOTAL | 2,243,437 | 6.11 | 2.54% |
| Sacramento Valley | | | |
| Butte | 106,658 | 0.41 | 2.26% |
| Colusa | 130,851 | 0.61 | 2.58% |
| Glenn | 111,747 | 0.42 | 2.30% |
| Sacramento | 80,029 | 0.22 | 2.34% |
| Solano | 83,183 | 0.26 | 2.40% |
| Sutter | 119,301 | 0.55 | 2.74% |
| Yolo | 147,605 | 0.49 | 2.43% |
| TOTAL | 779,373 | 2.96 | 2.43% |
| Central Coast | | | |
| Monterey | 107,251 | 0.28 | 1.57% |
| San Luis Obispo and Santa Barbara | 125,976 | 0.34 | 1.45% |
| TOTAL | 233,227 | 0.61 | 1.51% |
| Imperial Valley | | | |
| Riverside and San Bernardino | 54,482 | 0.31 | 2.33% |
| Imperial | 211,559 | 1.70 | 2.53% |
| TOTAL | 266,041 | 2.01 | 2.43% |
| STATE TOTAL | 3,522,079 | 11.7 | 2.38% |

Emission flux totals of $NH_3$ for fertilized sites in California's Central Valley show consistency of emissions factor estimates, regardless of the crop types and fertilizer amounts. Total measured $NH_3$ losses for the fertilizer applications ranged from less than 0.1 to 0.7 g N-$NH_3$ m-2 (equal to 0.9 to 6.2 lbs. N-$NH_3$ emitted per acre). The estimated $NH_3$ emission factor values for the field sites analyzed to date range from 0.05% to 6.6% of total applied N fertilizer with an average at about 3.2% of applied nitrogen.

Field flux measurements imply that the single most important factor affecting the $NH_3$ emission rates from cropped sources in the Central Valley is the amount of chemical fertilizer applied. Field flux measurements suggest that other significant limiting factors of $NH_3$ emission rates from fertilizers include soil pH and the method of N fertilizer application. When the fertilizer ammonia emission factors developed through this research are used to calculate statewide ammonia emissions for fertilizer application, the average fertilizer $NH_3$ emission factor for California is 2.4% of the total applied N fertilizer.

Statewide emissions of $NH_3$ directly from chemical fertilizer applications are estimated to total nearly 12 x 106 kg N-$NH_3$ annually. The San Joaquin Valley accounts for just over one-half of the state's total annual emissions of $NH_3$ directly from agricultural application of fertilizers. On the basis of DWR crop types, it appears that the generalized categories of field crops and truck crops each account for about one-third of the state's total annual emissions of $NH_3$ directly from chemical fertilizer sources. Grain, pasture grass, and rice crop categories also contribute large fractions of the state's total annual emissions of $NH_3$ directly from chemical fertilizer sources.

## Ammonia Flux Profiles for Various Soil and Vegetation Communities in California

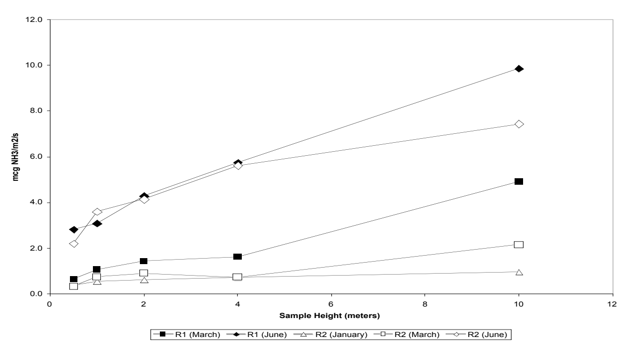
In the second phase of the project, atmospheric ammonia was sampled using the same active denuders co-located with wind instruments on a mast from near the soil surface to a height of 10m. $NH_3$ flux profiles were calculated from the data for a variety of soil/vegetation communities in central California. Profiles were calculated from samples taken several times during the season at the same location. Sites included rangeland in the Sierra Nevada foothills, various crops, and a dairy operation in the San Joaquin Valley. The magnitude and characteristics of the $NH_3$ flux profiles were compared to similar data from other research outside California and correlations with air temperature and diurnal differences were similar to those found elsewhere. Some indication of $NH_3$ absorption by active vegetation was found under circumstances where ambient concentrations were high.

Ammonia is one of the end products of organic matter decomposition by soil fungi and bacteria. Some $NH_3$ will find its way to the atmosphere and, under certain soil conditions, there may be significant volatile losses. The fate of the $NH_3$ after it reaches the atmosphere is less well known. The formation of secondary particles, $PM_{2.5}$ described above, is certainly one possibility. However, the fate of $NH_3$ in the microclimate near active vegetation appears to be complex. The interior structure of the typical plant leaf is adapted to absorb atmospheric $CO_2$ for photosynthesis. The diffusive characteristics of $NH_3$ in the atmosphere are likely to be similar to $CO_2$ suggesting the possibility of $NH_3$ absorption as well. Harper et al. (1983) found $NH_3$ losses to the atmosphere from tropical pastures in Australia after fertilization and at various other times through the season. $NH_3$ losses were correlated with high air temperatures and solar radiation levels. Absorption by vegetation was observed during the same study correlated with dawn and dusk periods. Harper et al. (1996), on temperate grassland in Georgia, found emissions after fertilization but again measured $NH_3$ absorption by the vegetation. He estimated 6% of the N in the vegetation was absorbed as atmospheric $NH_3$ in the cooler part of the growing season and 11% in the summer. An earlier investigation by Harper and Sharpe (1995) on irrigated corn in Nebraska used 15N labeled fertilizer to show both emission and absorption of $NH_3$ by the crop at various times through the season. Some absorption of 15N labeled $NH_3$ by crops that had not been fertilized was detected, indicating the possibility that emission of $NH_3$ from fertilized plots was absorbed by nearby vegetation. $NH_3$ absorption was correlated with air temperature, solar radiation, soil moisture, and soil N levels but primarily with $NH_3$ concentration in the atmosphere. High atmospheric $NH_3$ resulted in absorption regardless of the other factors. Absorption of $NH_3$ has been reported in other research, notably Porter et al. (1972), where corn seedlings were placed in an atmosphere spiked with labeled 15$NH_3$. They found absorption of up to 30% of $NH_3$ in a 24-hour period.

The somewhat contradictory findings sited above illustrate the complexity of $NH_3$ transport in the soil-plant-atmosphere system. The data presented below are from a variety of soils and vegetation communities in California. The same sites were sampled at various times of the year. Sampling was continuous over several days and included separate diurnal samples. The results, to date, suggest both emission and absorption correlated with many of the same factors seen in the previous research.

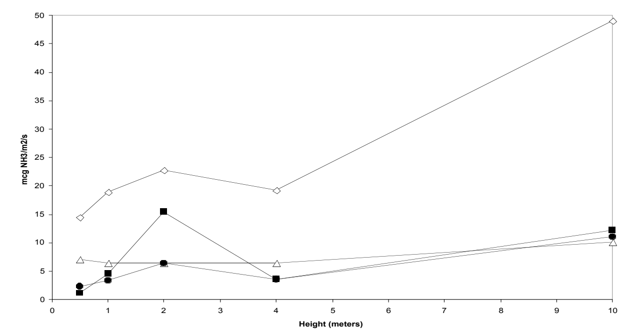
A correlation between air temperature and $NH_3$ levels was anticipated. One of the reasons for sampling the same site at various times through the year was to verify that relationship. The magnitude of the flux and the characteristics of the vertical profile did appear to correlate with the average air temperature. The San Joaquin Experimental Range is a 2000 Ha field site administered by CSU Fresno for the US Forest Service. Two sampling sites were designated and sampled every few months beginning in January of 2002. Some of the data is shown below in Figure 3. The average air temperature during the sampling in January was 8.6 C. In March the average was 14.6, and in June the temperature averaged 24.0 C. The lowest $NH_3$ values were in January, the highest in June. There were two sampling sites and both sets of flux profiles appear to be correlated with temperature. Site R1 was in an open meadow of annual grasses. Site R2 had brush and trees enclosing a small area of grasses. It is likely that the air temperature, particularly in the shade, near the soil surface was lower at R2. The $NH_3$ flux values were higher for the R1 site sampled at the same time as the R2 site, particularly at 10m. The difference may be due in part to temperature. The R1 site had no tall vegetation within 50m of the mast compared to the R2 site where there were 20m trees within 5m of the mast.

**Figure 3. Ammonia flux profiles for two rangeland sites located 40 km north of Fresno at an elevation of 300m. Each line represents an average of three to five days of continuous sampling. The two sites were about 200m apart. R1 (closed graph symbols) was open grassland with no trees or brush within 50m of the mast and R2 (open symbols) had a higher level of vegetation; a mix of grass, brush and trees.**




A second relationship between an environmental factor and the atmospheric $NH_3$ flux profiles is the distinct, diurnal difference. In each sampling episode, to date, at least one day of collection was divided into a day and night sample. Nearly every one of those diurnal sample pairs showed considerably more $NH_3$ during the day compared to the night sample. Figure 2 is data from a field planted to barley. There were three periods of sampling from the seedling stage in November of 2001 to the harvest in March 2002. The average of the flux profiles for each sampling period showed the same correlation with air temperature as the rangeland in Figure 3. Figure 4 shows the diurnal differences for the last sampling in early March.

**Figure 4. Ammonia flux profiles over a barley crop just prior to cutting for silage. Plant height was about 1m. Daytime samples are designated by (d) in the legend and an open symbol on the graph. Night data is shown as (n) and a closed symbol.**

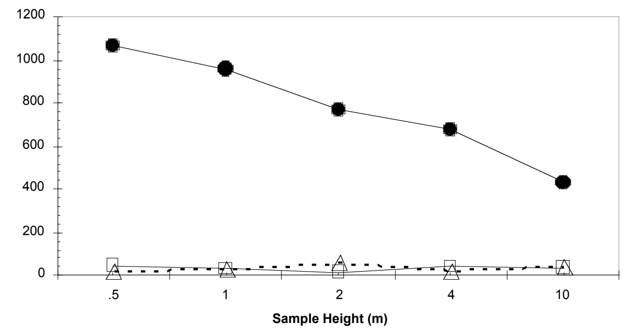



The two night samples are lower in magnitude and show less profile difference over the sampling heights. The day sample for March 11 is typical of day samples for most of the vegetation types in the study. The magnitude is considerably higher and there is a more pronounced gradient of flux values between the 10m sample and the 0.5m sample. The other day sample, March 8, appears to violate the postulated correlation. Its profile is more characteristic of a night sample. March 11 was a typical spring day in the San Joaquin Valley. The average temperature was 19.9 C; relative humidity was 41%, with a light wind. March 8 was a cool day (13.5 C) near the end of a storm event that dropped 12mm of rain. The air temperature during the storm was more characteristic of nighttime levels. It is also likely the moisture in the air reduced the $NH_3$ values. Increased atmospheric moisture, either elevated humidity or precipitation, has been linked to lowered $NH_3$ levels in previous work.

The $NH_3$ absorption by active vegetation that was suggested in Harper's research also appears to apply to the data collected for this study. Many of the flux profiles shown in the previous figures indicate a gradient of $NH_3$ from the atmosphere to the soil/vegetation surface. While the transport pathways in the microclimate from the surface up to 10m are likely to be complex and variable for different times of the day and season, it is possible to speculate that the vegetation is acting as a net absorber of $NH_3$ when the flux profile shows a steep gradient from the ambient atmosphere toward the surface. Both Harper and Porter's work concluded absorption of $NH_3$ by the plant from the air was related to the amount of atmospheric $NH_3$ surrounding the plants. Harper noted several factors that sometimes correlated with absorption but stated the concentration of $NH_3$ in the air was the most consistent factor affecting $NH_3$ absorption, and found it would supersede the other factors. Atmospheric $NH_3$ concentrations found by Harper to result in measurable absorption were less than most of those monitored at 10m in this study. The ability of a vegetation/soil community to both emit and absorb atmospheric $NH_3$ may be illustrated by data from another sampling location of this project. A dairy near Merced was chosen for a series of air quality samples and a variety of constituents including $NH_3$ were collected. Ammonia profiles were measured at three sampling locations at the dairy.

The $NH_3$ flux profile for the DJ1 (upwind location) resembles those found for similar crops in central California. The winter silage is not unlike the barley and corn crops shown in Figures 2 and 3, and the flux profiles are similar in both magnitude and shape. The Lagoon sampling location, DJ2, shows a significant increase in $NH_3$ magnitude, which is to be expected from the 3500 Holsteins located between the two sampling points. Most of the $NH_3$ is probably from catalysis of urea by urease in the soil of the free stall, open areas, and lagoon system of the CAFO. The sampling site was located 5m from the downwind edge of the lagoon. Absorption of $NH_3$ from the air by a surface across which the air passes may also be indicated by the $NH_3$ flux profile at DJ5, the sampling site downwind from DJ2. The typical wind direction is directly from DJ2 to DJ5. The primary influences on the $NH_3$ profile between those two points would be various dispersion mechanisms in the atmosphere and emission/absorption of $NH_3$ by the surface. The fluxes downwind of the field have dropped to those monitored at the upwind site, DW1, which would be considered background. The surface over which the air passed from DJ2 to DJ5 was the winter silage crop. The high ambient $NH_3$ levels at DJ2 would, according to Harper, indicate the absorption of atmospheric $NH_3$ by the leaves of the vegetation. The reduction of the fluxes to background levels after crossing 500m of vegetation appears to be strong evidence that vegetative absorption of atmospheric $NH_3$ is taking place.

**Figure 5. Ammonia flux profiles associated with a Central Valley Dairy. The upwind was 50m NW of the first dairy barn, the lagoon sample was along the southern edge of the lagoon, and the Far Downwind sample was taken at the SE corner of the field downwind of the dairy, approximately 500m from the lagoon.**




A number of the project's initial assumptions appear to be on the way to confirmation and the significance of some others may be greater than was originally assumed. It certainly appears that atmospheric $NH_3$ is higher during the day compared to night. The increase in $NH_3$ emissions with higher air temperatures suggested by Harper and others is also consistent with the data collected in this research. The characteristic shape of most flux profiles suggests a net absorption of $NH_3$ near the surface. Knowledge of the N cycle, particularly for cultivated, fertilized crops would suggest there is a significant amount of $NH_3$ produced by soil microbes. The fate of the $NH_3$ produced in the soil is complex and not well documented, but emission of a portion of it to the atmosphere is almost a certainty, as modeled by CASA. The intriguing suggestion, originally from Harper and others is the fact that $NH_3$ absorption by vegetation is as viable a fate for atmospheric $NH_3$ as is the hydrolysis by rain and dew, dry deposition, and the combination with $NO_x$ and $SO_x$ to form secondary $PM_{2.5}$ particles; the reason this study was commissioned.

## Ammonia Emissions From N Applied in a Site Specific Manner

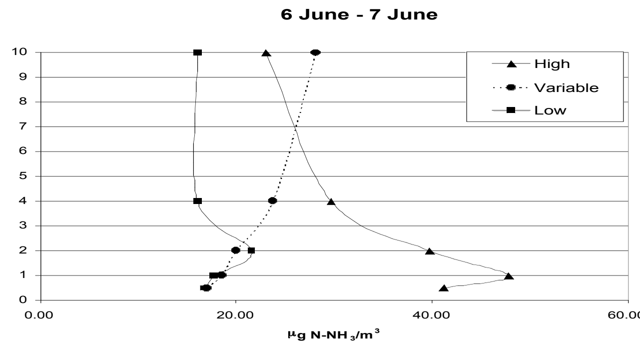
Cotton ranks as one of the major crops in California in terms of total acreage and income. Most cotton production in the state of California takes place in the San Joaquin Valley. Fertilizer rates were shown in the previous phases of this project to be a factor in ammonia volatilization. The objective of this study was to evaluate the effect of fertilizer rate on ammonia emissions following a variable rate fertilizer application. If applying a reduced rate of nitrogen fertilizer reduced ammonia emissions, than variable rate technology, which only places fertilizer where it is needed, would reduce ammonia emissions as well as decrease inputs for cotton growers. This is significant in that not only are growers saving money on nitrogen fertilizers, but also as less ammonia is emitted there is a reduced environmental impact.

A nitrogen fertilization trial was conducted on a cotton crop (Phytogen 72) in the years 2003 and 2004 near Lemoore, California by the University of California (FREP Contract #01-0507). The objective of the trial was to evaluate various rates of nitrogen fertilizer as well as a variable rate application on a cotton crop. The trial was a completely randomized design replicated four times. Four different rates were evaluated including a low, medium, high, and variable or prescribed rate. The fertilizer applied was anhydrous ammonia shanked into the soil at a depth of 10cm. The rates for the 2003 test were 56, 127, and 198 kg N ha. The next year rates evaluated were 31, 131 and 230 kg N ha for the low, medium, and high plots, while the variable rate averaged out to be 189 kg N ha. Plots were eight rows across or 7.7m and ran the length of the field approximately 500m. Ammonia sampling was conducted within some of the nitrogen trial plots before, during, and after the fertilizer application in order to detect the ammonia emissions from differing rates of applied anhydrous ammonia. In plots where ammonia-sampling sites were placed, plot sizes were increased to 32 rows or 31m in order to create a larger fetch for the samples. Ammonia samples were collected using the same methodology as in the previous studies at sunrise and sunset in order to capture diurnal ammonia variations.

Atmospheric ammonia concentrations increased appreciably over background concentrations the night after the application in all treatment plots (low variable, and high) in 2003 and 2004. Higher concentrations of ammonia were monitored in the high rate plot compared to the low and variable rate plots (Figure 6) the night after the application.

After two days, ammonia concentrations in all plots (low, variable, and high rates) were back close to background concentrations.

Figure 6. Ammonia concentration profiles the night after the nitrogen application.




Regression analyses were run on ammonia emissions concentrations in treatment plots versus rates of applied anhydrous ammonia fertilizer in order to evaluate the link between the two variables. Samples with a higher slope in the equation of the regression were considered to more closely link atmospheric ammonia concentration to applied nitrogen.

Slope values increased after application of nitrogen, indicating that applied amount of nitrogen has an effect on ammonia emissions. Values of regression slopes decreased when ammonia emissions had ceased (Table. 3).

Atmospheric ammonia concentrations increased significantly over background concentrations the night after the application in all treatment plots (low variable, and high) in 2003 and 2004. The highest concentrations of ammonia detected both years occurred during the night after the application. After levels of ammonia peaked during the night after the application, they decreased close to background concentrations two days after the application

The method employed to detect differences in levels of ammonia emissions was successful in quantifying higher concentrations of ammonia in the plots with the highest nitrogen rates. Slopes of regression analysis identified an increase in atmospheric ammonia within plots fertilized with an increased amount of nitrogen fertilizer after a short post application lag period. This lag period between application and emissions indicates most emissions occur after the actual application and not during the act of application. This link between applied nitrogen fertilizer and atmospheric ammonia decreased with time after the application.

**Table 3. Summarization of data collected at 0.5 m during 2003 trial. * Indicates the beginning of ammonia emissions due to the fertilizer application. ** Indicates the ammonia emissions from fertilizer application has ceased**

| Sample Height - 0.5 m | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Concentrations | | | | |
| Date | Sample Period | Sample Description | High | Variable | Low | Regression Slope | Wind Speed |
| 5 June | Day | Day before application | 22.0 | 16.5 | 11.4 | 0.0746 | 1.8 |
| 5 June - 6 June | Night | Night before application | 20.1 | 23.2 | 16.0 | 0.0289 | 0.9 |
| 6 June | Day | Day of application | 7.6 | 17.6 | 14.4 | -0.0479 | 1.9 |
| 6 June - 7 June | Night | Night after application | 41.1 | 17.0 | 16.8 | 0.1711 * | 1.2 |
| 7 June | Day | Day after application | 18.4 | 18.3 | 7.3 | 0.0782 | 1.9 |
| 7 June - 8 June | Night | 2 nights after application | 15.9 | 20.7 | 21.8 | 0.0451 | 1.1 |
| 8 June | Day | 2 days after application | 17.0 | 21.9 | 17.4 | -0.0028 ** | 1.5 |
| 8 June - 9 June | Night | 3 nights after application | 17.6 | 16.1 | 29.9 | -0.0862 | 0.9 |
| 9 June | Day | 3 days after application | 17.9 | 16.5 | 18.2 | -0.0022 | 1.5 |
| 9 June - 10 June | Night | 4 nights after application | 14.2 | 16.9 | 15.7 | -0.01 | 1.6 |
| 10 June | Day | 4 days after application | 41.1 | 15.7 | 13.4 | -0.1953 | 1.3 |
| 10 June - 11 June | Night | 5 nights after application | 18.5 | 23.5 | 14.4 | -0.029 | 1.5 |

Variable rate fertilizer decreases the net loss of ammonia volatilized, as less fertilizer is applied when compared to a blanket application of a high rate. Implementing variable rate applications will not only reduce input costs but will reduce the environmental impact of the possible over-application of fertilizers. New applications of variable rate technology must be investigated for benefits such as those observed in this study.

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# Evaluation of Polyacrylamide (PAM) for Reducing Sediment and Nutrient Concentration in Tailwater from Central Coast Vegetable Fields

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## Introduction

Current state and federal water quality regulations, such as the conditional waiver for agricultural discharge and proposed total maximum daily loads (TMDL) for nutrients and sediments, will require that growers implement best management practices that minimize impairments to surface and groundwater quality. While most growers are currently using recommended practices such as drip irrigation, cover crops, and integrated pest management to reduce the impacts of agriculture on water quality, additional management tools could help growers achieve more dramatic improvements to water quality.

Growers who produce vegetables and row crops on highly erodible soils, such as the east side of the Salinas valley or sloped fields in the Elkhorn watershed, have a difficult challenge in reducing sediment and nutrient levels in runoff. Though many growers are using sediment basins and drip irrigation to minimize runoff and capture sediments, these practices are costly and may not fully achieve water quality targets. Our initial trials evaluating polyacrylamide (PAM), a chemical polymer, for use in sprinkler and furrow systems, demonstrated significant reductions in sediment and nutrient concentration in irrigation runoff.

## A brief primer on PAM

Polyacrylamide (PAM) is a polymer used to stabilize soil and prevent erosion. Various forms of PAM exist, but the type used for erosion control is a large, negatively charged molecule (12-15 megagrams per mole) that is water soluble. PAM is commercially available in dry granular, emulsified liquid, and dry tablet forms, and costs as low as $2 to $4 per pound depending on the formulation, supplier, and cost of the raw materials used for manufacturing PAM (ie. natural gas). Non-agricultural uses of PAM include waste and potable water treatment, processing and washing of fruits and vegetables, clarification of juices, manufacturing of cosmetics, and paper production.

***Use of PAM for irrigation and erosion control***
Beginning in the early 1990's numerous studies demonstrated that low application rates of PAM (1 to 2 lb/acre) reduced runoff and improved water quality in furrow systems by stabilizing the aggregate structure of soil, by improving infiltration, and by flocculating out suspended sediments from irrigation tailwater. Most of the research and demonstrations of PAM for irrigation were conducted in Idaho and Washington states where soils are very erodible. By 1999, almost 1 million acres of land were annually treated with PAM in the northwest of the United States. Additionally, growers in the San Joaquin Valley and the Bakersfield areas of California have been using PAM to reduce soil erosion during irrigation events.

***Application methods***

Most applications of PAM have been conducted in furrow systems by adding dry or liquid product to water flowing in the head ditch or the main line (if gated pipe is used) at a rate to achieve a 2.5 to 10 ppm concentration in the furrow water. The application can be made continuously during the irrigation or until the water advances almost to the end of the furrows. An alternate application method, called the "patch method" involves applying granular PAM to the first 3 to 5 feet of the head of each furrow. The granular PAM slowly dissolves during the irrigation, releasing product into the water. Applications of PAM into sprinkler systems require equipment for injecting concentrated liquid PAM into a pressurized main line at flow rates between 0.25 to 2 gallons per minute to treat a 30- to 100-acre field irrigated with solid-set impact sprinklers.

***Human and environmental safety***

PAM has a very low toxicity to mammals and is safe to handle, but precautions should be taken to minimize skin and eye exposure, and to avoid breathing dust from dry material. PAM can cause skin irritation in sensitive individuals. PAM becomes very slippery when wet so spills should be cleaned with a dry absorbent before attempting to wash it. PAM is sometimes confused with acrylamide monomer, a precursor in the manufacturing of PAM. Acrylamide monomer, a potential neurotoxin, has a high, acute toxicity in mammals. The Federal EPA requires that PAM sold for agricultural uses contain less than 0.05% acrylamide monomer. In soil, PAM degrades by physical, chemical, biological, and photochemical processes, but it does not decompose into the acrylamide monomer.

Environmental studies of PAM have not shown any negative effects to the aquatic organisms. Anionic (negatively charged) PAM has a very low toxicity to fish, daphnia and algae. A previous study of the movement of PAM from agricultural fields showed that less than 3% of the applied product remained in the runoff leaving the field. The remaining PAM in the tailwater was almost completely removed through adsorption to suspended sediments as the water flowed a distance of 300 to 1000 ft in the tailwater ditch.

## Evaluation of PAM in Central Coast vegetable fields

Although research in other parts of the United States has demonstrated that PAM can reduce soil erosion during irrigations, few if any evaluations of this practice have been conducted in vegetable and row crop fields on the Central Coast. Considering the important need to identify effective conservation practices that can improve farm water quality, we conducted a series of field trials to evaluate the effect of PAM[1] on infiltration, runoff, and the concentration of sediment and nutrients in tailwater from furrow and sprinkler systems.

***Furrow systems***

PAM has been most successfully used to improve furrow irrigation. We evaluated the effect of PAM on infiltration and the concentration of sediments and nutrients in tailwater from furrows of six commercial vegetable fields in the Salinas Valley using a recirculating infiltrometer. Water, treated with 10 ppm of PAM was first added to a 20-ft length of furrow. The water reaching the end of the furrow was recirculated to the head using a bilge pump. Untreated water was added from a tank to the head of the furrow to maintain a constant depth of water. Infiltration was estimated by measuring the rate that the tank emptied. Our results demonstrated that the pretreatment with PAM in the furrow water was sufficient to reduce the suspended sediments and nutrients in the tailwater, but the PAM treatment did not have a consistent effect on infiltration. PAM significantly increased infiltration in a silt loam soil and significantly reduced infiltration in clay loam and sandy loam soils (Table 1). The PAM treatment reduced suspended sediments and turbidity in the runoff from all soil types. On average, the PAM treatment reduced suspended sediments by 86% (Table 2). Additionally, the PAM treatment reduced total nitrogen, soluble P, and total P in the tailwater runoff (Tables 3 and 4) which corresponded to a 80% reduction in total P, 42% reduction in soluble P, and a 65% reduction in total N for all soil types tested. The concentration of total phosphorus in the tailwater decreased as the concentration of suspended sediments in the tail water was reduced (Figure 1). The PAM treatment significantly reduced nitrate concentration in the furrow tailwater of only one of the soil types tested.

[1]Amber1200D, formerly Superfloc A-836, Amber Chem. Inc

**Table 1. Effect of PAM pretreatment (10 ppm) on final infiltration rate and total infiltration in furrows of six soil types from the Salinas Valley. Treatment means represent the average of four replications.**

| | Final Infiltration Rate | | Total Infiltration[2] | |
|---|---|---|---|---|
| Soil Type | PAM | Control | PAM | Control |
| | --- mm/hr --- | | ----- mm ----- | |
| Mocho silt loam | 7.5 | 3.5 [1] | 18.4 | 16.9 |
| Metz complex | 7.9 | 7.3 | 19.8 | 18.9 |
| Rincon clay loam | 2.6 | 4.0 | 13.7 | 13.9 |
| Salinas clay loam | 5.2 | 5.0 | 18.0 | 26.6 |
| Chualar loam | 5.8 | 4.2 | 18.7 | 18.6 |
| Chualar sandy loam | 159.0 | 197.3 | 247.5 | 349.5 |
| Average | 32.4 | 38.4 | 57.6 | 76.5 |

[1] = treatment means are statistically different at the 95% confidence level.
[2] total infiltration during 1.5 hours

**Table 2. Effect of PAM pretreatment (10 ppm) on sediment concentration and turbidity of furrow tailwater for six soil types from the Salinas Valley. Treatment means represent the average of four replications.**

| | Total Suspended Solids | | Turbidity | |
|---|---|---|---|---|
| Soil Type | PAM | Control | PAM | Control |
| | --- TSS mg/L --- | | --- Turbidity NTU --- | |
| Mocho silt loam | 244 | 2024 | 55 | 1977 |
| Metz complex | 156 | 669 | 18 | 473 |
| Rincon clay loam | 412 | 1715 | 51 | 1013 |
| Salinas clay loam | 240 | 2759 [1] | 59 | 2437 |
| Chualar loam | 306 | 2580 | 129 | 2992 |
| Chualar sandy loam | 36 | 165 | 24 | 183 |
| average | 224 | 1592 | 54 | 1459 |

[1] = treatment means are statistically different at the 95% confidence level.

**Table 3. Effect of PAM pretreatment (10 ppm) on nitrate and total nitrogen concentration of furrow tailwater for six soil types from the Salinas Valley. Treatment means represent the average of four replications.**

| | Nitrate-Nitrogen | | Total Nitrogen[2] | |
|---|---|---|---|---|
| Soil Type | PAM | Control | PAM | Control |
| | --- $NO_3$-N mg/L --- | | --- TKN mg/L --- | |
| Mocho silt loam | 1.30 | 1.95 | 2.38 | 6.38 |
| Metz complex | 23.13 | 23.33 | 1.43 | 2.25 |
| Rincon clay loam | 22.38 | 22.58 | 1.75 | 3.08 |
| Salinas clay loam | 0.71 | 1.23 [1] | 1.38 | 6.95 |
| Chualar loam | 2.03 | 2.09 | 2.20 | 8.45 |
| Chualar sandy loam | 1.52 | 1.46 | 0.43 | 0.73 |
| Average | 8.24 | 8.48 | 1.57 | 4.48 |

[1] = treatment means are statistically different at the 95% confidence level.
[2] Total Kjeldahl Nitrogen

**Table 4. Effect of PAM pretreatment (10 ppm) on soluble and total phosphorus concentration of furrow tailwater for six soil types from the Salinas Valley. Treatment means represent the average of four replications.**

| | Soluble Phosphorus | | Total Phosphorus | |
|---|---|---|---|---|
| Soil Type | PAM | Control | PAM | Control |
| | --- Soluble P mg/L --- | | ----- Total P mg/L ---- | |
| Mocho silt loam | 0.35 | 0.78 [1] | 0.85 | 5.30 |
| Metz complex | 0.09 | 0.16 | 0.35 | 1.33 |
| Rincon clay loam | 0.31 | 0.44 | 0.68 | 1.88 |
| Salinas clay loam | 0.36 | 0.64 | 0.80 | 5.40 |
| Chualar loam | 0.28 | 0.46 | 0.58 | 3.23 |
| Chualar sandy loam | 0.09 | 0.12 | 0.14 | 0.30 |
| Average | 0.24 | 0.42 | 0.55 | 2.80 |

[1] = treatment means are statistically different at the 95% confidence level.

**Figure 1. Relationship between suspended sediments and total phosphorus in furrow tailwater, treated and untreated with PAM, for six soils in the Salinas Valley.**

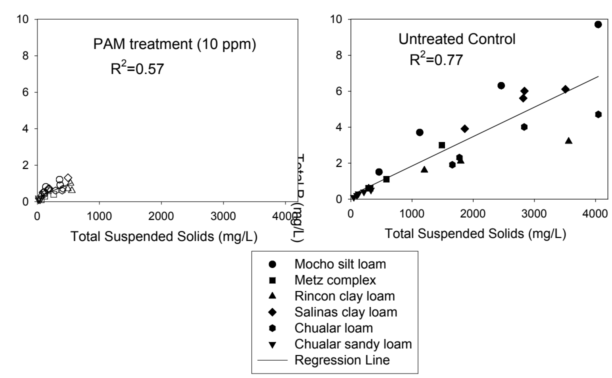

Table 5. Effect of PAM on nutrient and sediment concentration in runoff from solid set sprinklers. Treatment means represent the average of four replications.

| Treatments | PAM Application | Applied Water | Total Kjeldahl N | $NO_3$ -N | P (soluble) | P (total) | Total Disolved Solids | Total Suspended Solids | Turbidity | Runoff | (%) | Sediment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | lb ai/acre | inches | mg/L | | | | | | NTU | gal/acre | (%) | lb/acre |
| 1st Irrigation 7/9/04 | | | | | | | | | | | | |
| PAM | 0.73 | 0.78 | 2.83 [1] | 6.03 | 0.41 | 0.55 | 905 | 72 | 66 | 1389 | 6.6 | 0.8 |
| Untreated Control | 0.00 | 0.86 | 5.20 | 3.56 | 0.61 | 2.83 | 885 | 900 | 2647 | 1138 | 4.9 | 8.5 |
| 2nd Irrigation 7/14/04 | | | | | | | | | | | | |
| PAM | 0.58 | 0.81 | 2.35 | 1.97 | 0.22 | 0.38 | 1073 | 32 | 39 | 1932 | 8.8 | 0.5 |
| Untreated Control | 0.00 | 0.84 | 5.13 | 1.51 | 0.39 | 2.05 | 905 | 786 | 1691 | 1947 | 8.5 | 12.8 |
| 3rd Irrigation 7/19/04 | | | | | | | | | | | | |
| PAM | 0.54 | 0.82 | 1.73 | 10.5 | 0.33 | 0.33 | 1103 | 20 | 16 | 976 | 4.4 | 0.2 |
| Untreated Control | 0.00 | 0.71 | 4.00 | 10.1 | 0.47 | 2.23 | 800 | 1205 | 3031 | 1507 | 7.9 | 15.1 |
| Average/Total | | | | | | | | | | | | |
| PAM | 1.85 | 2.41 | 2.30 | 6.2 | 0.32 | 0.42 | 1027 | 42 | 40 | 1432 | 6.6 | 1.5 |
| Untreated Control | 0.00 | 2.41 | 4.78 | 5.1 | 0.49 | 2.37 | 863 | 964 | 2456 | 1531 | 7.0 | 36.4 |

[1] = treatment means are statistically different at the 95% confidence level

### *Sprinkler systems*

For PAM to be a useful conservation practice on the Central Coast, it needs to be effective with sprinkler irrigation. However, much less information has been published about the use of PAM in sprinklers than in furrow systems. We conducted several field trials evaluating the effect of PAM on runoff from solid-set sprinklers in commercial vegetable fields. A concentrated solution of PAM was injected into the main line of the sprinkler system at a rate to achieve a 5 ppm concentration in the irrigation water. The applications were done during the irrigations between germination and thinning. Each PAM application was made during the first 30 minutes of the irrigation and again when significant ponding occurred in the furrows and continued until the end of the irrigation set. Application rates of PAM varied from 0.5 to 0.75 lb/acre per irrigation.

The results from these trials demonstrated that PAM significantly reduced sediment and turbidity in runoff from sprinklers. Results of three irrigations from a sprinkler trial conducted near Chualar are shown in Table 5. The application of PAM reduced sediment and turbidity levels in the runoff for all irrigations, which corresponded to a 95% reduction in sediment loss. Additionally, PAM significantly reduced runoff during the third irrigation. The effects of PAM on phosphorus and nitrogen concentration in sprinkler runoff were more variable than in the furrow trials. Total nitrogen and phosphorus concentration was significantly lower in tailwater from the PAM treatment than the untreated control. However, at another field site, the PAM treatment did not significantly reduce nitrogen and phosphorus in tailwater from the sprinklers, but it did significantly reduce sediment concentration (data not shown).

### *Lettuce yield*

The application of PAM may potentially improve lettuce yields by increasing water penetration and by reducing soil crusting. We found that the application of PAM did not affect box yield of romaine and head lettuce at the four field trials where we were able to conduct yield measurements (Table 6). The PAM treatment significantly increased box weight of romaine heads at one of the field trials. Since PAM was not applied in more than three irrigations for any one trial, we cannot conclude if more applications of PAM would affect yield.

Table 6. Effect of PAM on box yield and head weight of romaine and head lettuce.

| Trial Location | Box Weight PAM | Box Weight Control | Box Yield PAM | Box Yield Control |
|---|---|---|---|---|
| | lb/box | | box/acre | |
| King City[2] | 41.0 [1] | 39.1 | 760 | 731 |
| Chualar-a[3] | 21.9 | 21.1 | 1145 | 1130 |
| Soledad[4] | 39.3 | 38.5 | 1179 | 1190 |
| Chualar-b[3] | 24.0 | 24.6 | 944 | 957 |
| Average | 31.5 | 31.0 | 1007 | 1002 |

[1] = treatment means are statistically different at the 95% confidence level
[2] romaine
[3] romaine hearts
[4] iceberg

## Conclusions

Our preliminary trials demonstrated that applying polyacrylamide at low rates through sprinkler and furrow systems can dramatically reduce sediment levels in irrigation runoff and potentially reduce total phosphorus and nitrogen concentrations. The effect of PAM on infiltration and runoff was dependent on soil type, but on most of the Central Coast soils that we tested, the low rates of PAM had no significant effect on infiltration. Although our initial results are encouraging, further trials will be needed to determine if PAM can consistently reduce nutrient concentration in runoff from sprinklers, and to determine the optimal dose and application strategy for improving water quality.

## Acknowledgements

We greatly appreciated the grower cooperation from American Farms, Christensen and Giannini, Costa Farms, D'Arrigo Bro., Huntington Farms, John Gill Ranch, and Rio Farms, and financial support from the CDFA Fertilizer Research and Education Program.

# WATER CONSERVATION IN COVER-BASED CROPPING SYSTEMS

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## INTRODUCTION

Agricultural runoff is potentially a key pathway for loss of nutrients from farm soils. Nutrient losses to runoff result in inefficient use of fertilizer and mean both higher costs to farmers, as they pay to replace the lost nutrients, and higher costs to society, as it pays to clean up degraded waterways. The degree to which agricultural runoff affects nonpoint source pollution of California's rivers, streams, and lakes, however, is not fully understood. The purpose of this project is to quantify relationships between tillage and fertility management, and runoff and nutrient loss, from soils farmed using organic, low-input, and conventional practices.

Conservation tillage (CT), with necessitated changes in irrigation system design and efficiency, and cover-cropping, are two avenues for reducing runoff and decreasing nutrient losses. These management alternatives also have the potential to improve many other aspects of farm management for California growers, including reducing labor and fuel costs, increasing soil water storage, decreasing water usage, decreasing dust emissions, increasing carbon sequestration, and increasing net revenues. Few studies have been done in California to evaluate the separate and/or combined effects of CT and cover-cropping, on runoff and consequent nutrient loss to surface waterways, in conventional or alternative production systems.

Measurements were made of runoff from plots at the Sustainable Agriculture Farming Systems (SAFS) research site at UC Davis, a long-term comparison of organic, low-input, and conventional farming systems, and from farm fields provided by SAFS grower-collaborators. Results of our study from the grower's fields during the 2003-2004 and 2004-2005 rain seasons show a stark contrast in runoff quantity between a field planted in a winter legume/oats cover crop (CC) and a field with no plant cover (NCC). Notably, the quantity of runoff discharged from the winter 2003 – 2004 CC field was less than one-tenth the runoff of the winter NCC field. In addition, the NCC treatment demonstrated significantly higher concentrations of sediment, P, $NH^{4}+$, and dissolved organic N over the rain season when compared to the CC treatment. For the summer of 2004 irrigation season, cumulative discharge from the winter CC field was estimated to be a 25% reduction compared to the winter NCC field discharge. This estimation is from discharge values only and does not include the subtraction of input values because they are unknown at this time. However, CT management of plots and fields produced greater loads of water constituents of concern compared to non-CT management. CT plots were within the first two years of management and so it appears that CT may take years to realize positive benefits for water quality.

**Figure 1. Winter 2004 - 2005 Total Suspended Solids (TSS), Dissolved Organic Carbon (DOC), Phosphate, Nitrate, and Ammonium as measured from the research plots at SAFS in three farming systems (Conventional, Low-input and Organic). Each of the farming system is split into two tillage practices: Conservation (CT) and standard tillage (ST)**

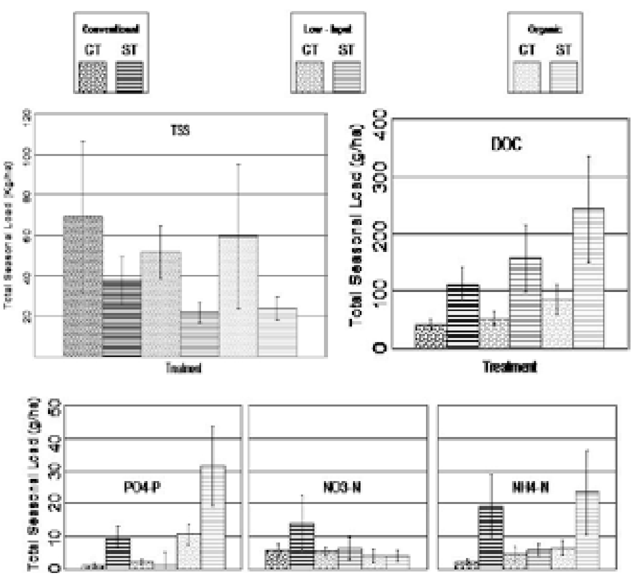
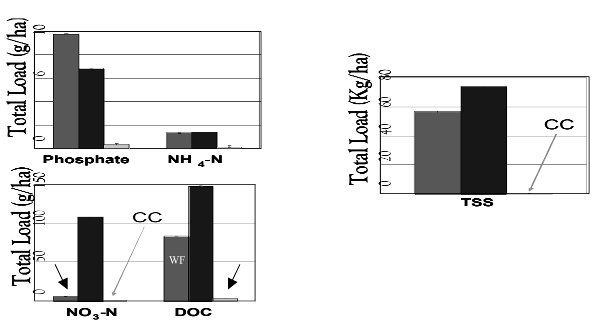



**Figure 2. Winter 2004 - 2005 Average Load of Phosphate, Ammonium, TSS, Nitrate, and Dissolved Organic Carbon measured from two grower's fields in Yolo County in three farming systems' winter fallow (WF), conservation tillage (CT), and cover cropped (CC) plots.**




# OBJECTIVES

1. Quantify discharge from research plots and farms using CC and CT compared to conventional agricultural practices.
2. Quantify non-point source pollution (NPSP) concentrations and loads in runoff.
3. Inform farmers, policymakers, and the general public about the usefulness of CC and CT in addressing nutrients losses.

# DESCRIPTION

During the last two years, we have addressed these three objectives by establishing a network of automated water samplers at the long-term UC Davis sustainable agriculture research plots and in grower fields in the Sacramento Valley. Water quality parameters identified include total suspended sediment (TSS), turbidity, inorganic phosphate and nitrogen, total dissolved nitrogen and phosphorous, dissolved organic carbon, and herbicides. Our research quantifies NPSP in discharge from conventional, low-input, and organic systems under either standard tillage (ST) or CT. The organic and low-input systems utilize winter legume cover crops (CC) as the primary nitrogen input. The CT systems incorporate practices that maintain at least 30 percent of the crop residue on the soil surface or reduce tillage passes by at least 40 percent.[i] The standard tillage systems mirror management practices typical of the surrounding area.

At the SAFS plots, one furrow from each plot was isolated to channel runoff into a 1m by 0.3 m diameter sump. At the end of each rain event, a sample was taken for analysis and the sump emptied. In the grower's fields, datalogger-equipped autosamplers were used to assess the affects of CC and CT, with samples and flow measurements taken during all runoff events.

# RESULTS AND CONCLUSIONS

Our research team has analyzed runoff quantity and quality data from five storm events during the 2003-2004 rain seasons and continuously from irrigation tailwater during the 2004-growing season. Preliminary analyses of growers' field data illustrate the effectiveness of CC at substantially minimizing discharge and NPSP loads. However, with the possible exception of sediment discharges, seasonal NPSP loading from winter fallow fields is not dramatic, suggesting that other field scale strategies (e.g., reconfiguring drainage patterns) may also be effective at meeting agricultural water quality goals.

Peak flow winter (2004-05) runoff velocities were 100% lower for CC field runoff events. That same year total discharge from grower fields was 18 times lower from the CC field. During the same period there was an average of 28 times the reduction of discharge from the grower CC fields compared to the fallow fields. It appeared that the cover crop was effective at reducing storm runoff soon after germination. On our research plots, however, CC showed higher discharge volumes NPSP loads compared to winter fallow treatments. This discrepancy between research plots and grower fields could be a result of differences in soil type or method of measurement. The results show additional research is required to understand the interplay between field size and configuration, soil type, and runoff monitoring strategies when developing predictive models for water quality concerns.

In winter 2004–2005, discharge from the low-input CT treatment was significantly higher than other treatments except for the organic standard tillage. This was somewhat consistent with that of the grower's CT vs. Winter Fallow comparisons. In both the research plots and the grower's field, CT management produced greater NPSP loads in runoff water compared to non-CT management, primarily due to higher cumulative discharge. In general, concentrations of various problem materials were similar for all treatments.

The increase in runoff from CT is unexpected. Results from the Midwest, where CT promotes infiltration, suggest the opposite. One possible explanation is that California soils generally have higher clay content, and are therefore more likely to create a soil crust that inhibits infiltration. It would be expected that after many years of CT, as soil near the surface accumulates organic matter, infiltration may be enhanced. All CT treatments were in the first or second year of management, and therefore were still building organic matter.

***SAFS Yiels***

In 2003, tomatoes were harvested in the conventional (CONV) and low-input (WLCC) on August 21, and in the organic (ORG) system on August 19-20. However, in 2004, tomatoes were harvested in the CONV system on August 7 and WLCC and ORG systems on August 16. In both years, hand harvest samples were taken approximately one week earlier and were generally consistent with the machine harvest yields. At the time of machine harvest most of the fruits became red across treatments. Yields in all farming systems were lower than the typical Yolo county average (33.8 tons acre-1 in 2003 and 40 tons acre-1 in 2004) in both years. In 2004, overall yields increased significantly over 2003 yields. In 2003, yields were significantly greater in the ORG farming system than in the CONV and WLCC farming systems. In 2004, however, there was no significant difference in yields among the farming systems. In 2003, overall yields were not significantly different between the standard tillage (ST) and conservation tillage (CT). In 2004, however, overall yields were greater under ST than under CT. Among the farming systems, CONV and ORG under ST had significantly greater yields than under CT but WLCC remained similar between the tillage practices.

Farming practices that preserve or enhance soil cover entering the rainy season appear to be effective at reducing cumulative runoff and, hence, NPSP loads. In general, research plots and grower fields demonstrate challenges to agricultural runoff monitoring. Adherence to strict CT practices can immediately reduce fuel costs, but the potential benefits to water quality may take years to realize. In the short term, growers may have other water conservation options, including reconfiguring fields to reduce runoff velocity, and thus erosion. Our research has shown that CC and CT can behave differently in California compared to other areas. On a farm scale, CC significantly reduces winter runoff but also may affect subsoil water recharge and soil moisture content at the time of planting. The potential for winter CC to alter the water budget of subsequent crops under furrow irrigation systems poses important questions, considering future water supply concerns. Additional research is needed to develop conceptual models that correlate water inputs and load reductions with alternative agricultural management practices in California. Such information would be beneficial to water quality stakeholders hoping to address future quality and supply issues.

[i]Standards as set by UC Cooperative Extension

# Increasing Yield of the 'Hass' Avocado by Adding P and K to Properly Timed Soil N Applications

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## Introduction

'Hass' avocado yields in California have averaged only 5,700 lbs./acre for the last 25 years (Arpaia, 1998). Experimentally determined leaf nutrient standards and replacement fertilization data related to yield and fruit size are generally lacking for the 'Hass' avocado in California. In a prior study, Lovatt tested the following hypothesis: Applying N to the soil at key stages of tree phenology will improve yield parameters. The 4-year study identified key stages in the phenology of the 'Hass' avocado that benefited from a double dose (2x) N (50 lbs./acre). The optimal application times for extra N corresponded to the following phenological events: 1) April – anthesis, fruit set and initiation of the spring vegetative flush; and 2) November – end of the fall vegetative flush and beginning of flower initiation. At these phenological stages soil-applied 2x N significantly increased the 4-year average yield and the 4-year cumulative yield, and increased by 70% yield of commercially valuable large size fruit. In addition, the April application significantly reduced the alternate bearing index for the 4 years of the study. In our similar, recently completed CDFA FREP-funded project on optimal timing of N fertilization, treatments producing the three numerically, but not statistically, greater cumulative yields for 2001 plus 2002 were the soil application of 3x N in April > the control > application of 2x N in November. In this study, each of the optimal times for applying N was incorporated into the control as a single dose of N (1x N, 25 lbs. N/acre). The optimal times that N was applied in the control treatment were: 1) April – anthesis, fruit set and initiation of the spring vegetative flush; 2) July – rapid increase in fruit size; 3) August – transition from vegetative to reproductive development, i.e., inflorescence initiation; and 4) November – end of the fall vegetative flush and beginning of flower initiation. No treatment significantly affected potential nitrate pollution of groundwater, but the control treatment did reduce its potential by a large numerical value. These two research projects were conducted in orchards with optimal nutrition based on standard leaf analysis. Moreover, the orchards were located in two climatically and edaphically different avocado growing areas of California to develop a strategy that works across avocado-producing areas of California. With the identification of the proper time to apply N, the next logical question is whether a greater response to N soil applications would be obtained if P and K were supplied simultaneously. Due to its immobility, P is commonly limiting. K runs a close second due to its high mobility and loss by leaching. In addition, avocado trees have a high demand for K because avocado fruit are rich in K, having more K/g fresh wt. edible fruit than bananas! This project tests the following hypothesis: Low available soil P or K at key stages in tree phenology will diminish the tree's response to properly timed soil-applied N.

## Project Objectives

The objectives of the proposed research are:

1. To quantify the effects of properly timed soil-applied: N vs. N supplemented with P and K on yield, fruit size and alternate bearing index in a commercial 'Hass' orchard with optimal nutrition based on leaf analysis, and

2. To disseminate the results of the research to the avocado growers of California. Treatments will continue for three years in order to obtain the Year 2 harvest.

## Project Description

To meet objective (1) two fertilizer treatments (N or NPK) were applied at the following times: (A) July and August; (B) November; (C) April; and (D) July, August, November, and April [best management practice for N (BMP N)]. These application times correspond to the following key stages of 'Hass' avocado tree phenology: July – period of rapid cell division and significant increase in fruit size; August – inflorescence initiation; November – end of the fall vegetative flush and beginning of flower initiation; and April – anthesis, fruit set and initiation of the spring vegetative flush. The treatments were replicated on 20 individual trees in a randomized complete block design. N was applied as ammonium nitrate to all treatments as follows: in treatment A, trees received only 50 lbs. N/acre/year, half in July and half in August. Treatments B and C each received 50 lbs. N/acre in November and April, respectively, with the remaining 50 lbs. N/acre applied equally in April, July and August or July, August and November, respectively. Treatment D received 25 lbs. N/acre in July, August, November, and April. Thus, all treatments received 100 lbs. N/acre/year, except treatment A. The N treatments had been in effect for four years prior to the addition of P and K to half of the trees in each treatment (20 trees per treatment) in Year 1 of this project. The rates of P and K were 15 and 90 lbs./acre/year, respectively, with trees receiving a double dose of P and K (7.5 and 45 lbs./acre, respectively) with the double dose of N (treatments B and C) and as a split application in July and August (treatment A). Treatments B and C, but not A, received the remaining P and K with the remaining N. Trees in BMP for NPK treatment received 3.75 lbs. P and 22.5 lbs. K in July, August, November, and April. The treatments are summarized in Table 1. The orchard is located in Somis, Calif. The trees are 24-year-old 'Hass' on clonal Duke 7 rootstock.

Harvest data included total kg fruit/tree. The weight of 100 randomly selected individual fruit/trees were used to calculate the total number of fruit per tree and the packout (fruit size distribution)/tree as kg and number of fruit of packing carton sizes 84 (99-134 g/fruit), 70 (135-177 g/fruit), 60 (178-212 g/fruit), 48 (213-269 g/fruit), 40 (270-325 g/fruit), 36 (326-354 g/fruit), and 32 (355-397 g/fruit). Two fruit per tree were evaluated for the length of time to ripen, peel color at maturity, and internal fruit quality (seed germination, vascularization, discoloration, decay). Fruit quality parameters are visually determined using a scale from 0 (none) to 4 (extensive, present in all four quarters of the fruit). All data were statistically analyzed using the General Linear Model procedures of SAS. ANOVA will be used to test for treatment effects on leaf nutrient concentrations, yield, fruit size, and fruit quality parameters. Means will be separated using Duncan's multiple range test at P=0.05.

**Table 1. N, P and K fertilization strategies.**

| | Month of application | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | April | | | July | | | August | | | November | | | Total | | |
| Treatment | N[z] | P | K | N | P | K | N | P | K | N | P | K | N | P | K |
| | lbs./acre | | | | | | | | | | | | | | |
| July + August N | – | – | – | 25 | – | – | 25 | – | – | – | – | – | 50 | – | – |
| July + August NPK | – | – | – | 25 | 3.75 | 22.5 | 25 | 3.75 | 22.5 | – | – | – | 50 | 7.5 | 45 |
| November N | 16.7 | – | – | 16.7 | – | – | 16.7 | – | – | 50 | – | – | 100 | – | – |
| November NPK | 16.7 | 2.5 | 15 | 16.7 | 2.5 | 15 | 16.7 | 2.5 | 15 | 50 | 7.5 | 45 | 100 | 15 | 90 |
| April N | 50 | – | – | 16.7 | – | – | 16.7 | – | – | 16.7 | – | – | 100 | – | – |
| April NPK | 50 | 7.5 | 45 | 16.7 | 2.5 | 15 | 16.7 | 2.5 | 15 | 16.7 | 2.5 | 15 | 100 | 15 | 90 |
| BMP N | 25 | – | – | 25 | – | – | 25 | – | – | 25 | – | – | 100 | – | – |
| BMP NPK | 25 | 3.75 | 22.5 | 25 | 3.75 | 22.5 | 25 | 3.75 | 22.5 | 25 | 3.75 | 22.5 | 100 | 15 | 90 |

[z] Nitrogen applied as ammonium nitrate.

In Year 3, when the second set of harvest data for which all trees received the fertilizer treatments for the full duration of the development of the crop (the 2005 and 2006 harvests), treatment effects on cumulative yield and on the alternate bearing index [ABI = (Year 1 yield - Year 2 yield) ÷ (Year 1 yield + Year 2 yield)] will be determined by ANOVA. Treatment effects across years will be determined by repeated measures analysis with year as the repeated measures factor. A cost/benefit analysis for each treatment will be calculated.

## Results and conclusions

The 2005 yield was the first in which all trees received the fertilization treatments prior to and during the initiation of floral development, flowering, fruit set, and fruit development. Trees receiving the low rate of NPK as a split application in July and August (a total of 50 lbs. N/acre, 7.5 lbs. P/acre and 45 lbs. K/acre, representing half the rate of all other trees except trees in the July + August N treatment, which received an equal amount of N without P and K) had a significantly lower yield as both kg and number of fruit per tree (Table 1). No other treatments affected total yield. No other treatment had a significant effect on total yield. The yield of trees receiving a double dose of N in April had the greatest yield (both kg and number of fruit) per tree but was not significantly different from any other treatment, despite an average of 45 to 75 more fruit per tree.

There were no significant treatment effects on the number of small size fruit (packing carton sizes 84 and 70) per tree (Table 2). However, the BMP N and BMP NPK treated trees had numerically more small fruit than all other treatments. Trees that received a double dose of N (50 lbs. N/acre) in November or April had significantly more commercially valuable large size fruit of packing carton size 60 than trees receiving the reduced rate of NPK as a split application in July and August ($P$=0.0753) and numerically more fruit of packing carton size 60 than all other treatments. Trees that received a double dose of N in April had significantly more commercially valuable large size fruit of packing carton size 48 than trees receiving the reduced amount of NPK as a split application in July and August and trees receiving the BMP N treatment ($P$=0.0232). No treatment affected the number of commercially valuable large size fruit of packing carton size 40. The total number of fruit of this size per tree was low (<20/tree). The number of fruit larger than size 40 per tree was even lower. There were significant treatment effects on the pool of all commercially valuable large size fruit, with the trees receiving the low rate of NPK as a split application in July and August having significantly fewer fruit in the combined pool of packing carton sizes 60 through 32 than all other treatments except trees receiving BMP N ($P$=0.0124). Trees receiving a double dose of N in April yielded 39 to 79 more fruit of packing carton sizes 60 through 32 than the remaining treatments, but the yield differences of large size fruit were not significantly greater.

**Table 2. Effect of soil-applied N or NPK fertilizer on yield and fruit size of the 'Hass' avocado.**

| Treatment | Total yield | Yield of packing carton sizes Σ84-70 (99-177 g) | 60 (178-212 g) | 48 (213-269 g) | 40 (270-325 g) | Σ60-32 (178-397) |
|---|---|---|---|---|---|---|
| | ---- no. of fruit ---- | | | | | |
| July + August N | 173 a | 31 | 55 ab | 68 ab | 18 | 142 a |
| July + August NPK | 40 b | 2 | 7 b | 20 c | 10 | 38 b |
| November N | 176 a | 31 | 66 a | 63 ab | 15 | 145 a |
| November NPK | 149 a | 22 | 52 ab | 65 ab | 10 | 127 a |
| April N | 222 a | 37 | 89 a | 82 a | 12 | 184 a |
| April NPK | 159 a | 23 | 52 ab | 69 ab | 13 | 136 a |
| BMP N | 161 a | 57 | 53 ab | 41 bc | 10 | 105 ab |
| BMP NPK | 177 a | 60 | 50 ab | 58 ab | 9 | 117 a |
| *P*-value | 0.0677 | 0.5559 | 0.0753 | 0.0232 | 0.5350 | 0.0124 |

[z]Means in a vertical column followed by a different letter are different at $P$=0.05 by Duncan's Multiple Range Test.

**Table 3. Effect of adding P and K to the N fertilization strategy on yield and fruit size of the 'Hass' avocado.**

| | | Yield of packing carton sizes | | | | |
|---|---|---|---|---|---|---|
| Treatment | Total yield | Σ84-70 (99-177 g) | 60 (178-212 g) | 48 (213-269 g) | 40 (270-325 g) | Σ60-32 (178-397) |
| | ---------- no. of fruit ---------- | | | | | |
| July + August N | 173 a | 31 | 55 a | 68 a | 18 | 142 a |
| July + August NPK | 40 b | 2 | 7 b | 20 b | 10 | 38 b |
| *P*-value | 0.0063 | 0.1149 | 0.0169 | 0.0142 | 0.2686 | 0.0112 |
| November N | 176 | 31 | 66 | 63 | 15 | 145 |
| November NPK | 149 | 22 | 52 | 65 | 10 | 127 |
| *P*-value | 0.6299 | 0.5703 | 0.5869 | 0.7052 | 0.3393 | 0.7411 |
| April N | 222 | 37 | 89 | 82 | 12 | 184 |
| April NPK | 159 | 23 | 52 | 69 | 13 | 136 |
| *P*-value | 0.2837 | 0.1390 | 0.1554 | 0.6348 | 0.2770 | 0.3453 |
| BMP N | 161 | 57 | 53 | 41 | 10 | 105 |
| BMP NPK | 177 | 60 | 50 | 58 | 9 | 117 |
| *P*-value | 0.8984 | 0.9893 | 0.8181 | 0.3276 | 0.7152 | 0.7982 |

[z]Means in a vertical column followed by a different letter are different at $P$=0.05 by Dunnett's two-tailed analysis.

To determine whether adding P and K to the N treatment had a significant positive or negative effect on total yield and fruit size, a pair-wise comparison was made where the addition of P and K was the only factor influencing yield parameters. The addition of P and K had a significant negative effect on total yield only for the low N rate split in July and August ($P$=0.0063) (Table 3). But interestingly, all total yields were numerically lower when P and K were added with N with the exception of the BMP treatment. There were no significant treatment effects on the number of small size fruit (packing carton sizes 84-70), but again the addition of P and K with the N resulted in a nonsignificant but lower number fruit in this size class with the exception of the BMP treatment. The addition of P and K had a significant negative effect on the yield of commercially valuable large size fruit of packing size 60 for the low N rate split in July and August ($P$=0.0169). In all other cases the addition of P and K with N resulted in a nonsignifcant lower number of fruit of packing carton size 60. The addition of P and K had a significant negative effect on the yield of commercially valuable large size fruit of packing carton size 48 for the low N rate split in July and August ($P$=0.0142), and adding P and K resulted in a nonsignificant lower number of fruit of packing size 48 for trees receiving a double dose of NPK in April. The number of fruit in the combined pool of commercially valuable large size fruit of packing carton sizes 60 through 32 was consistently lower with the addition of P and K with N with the exception of the BMP treatment.

All fruit was of excellent quality. The incidence of gray pulp, an internal fruit discoloration, occurred in typically less than one quarter of each individual fruit with the exception, albeit nonsignificant, of fruit from trees receiving NPK at the low rate as a split application in July and August (Table 4). There were significant treatment effects on the amount of vascularization present in the pulp of the fruit. Vascularization is the presence of xylem tissue in the pulp, making it "stringy," which is undesirable. The incidence overall was extremely low, occurring in less than 1/8 of each individual fruit, but was significantly higher in fruit from trees receiving the low rate of N as a split application in July and August than fruit from trees also receiving P and K at that time, fruit from trees receiving a double does of NPK in April, and fruit from trees receiving the BMP N treatment. Fruit from all other treatments had intermediate vascularization values that were not significantly different from fruit from the above treatments (Table 4). Fungal or bacterial decay was low and not affected by any treatment. Fruit from trees receiving a double dose of NPK in April took significantly fewer days to ripen (approx. 1.5 days

**Table 4. Effect of soil-applied N or NPK fertilizer on fruit quality of the 'Hass' avocado.**

| | Fruit quality parameters (average value for two fruit/tree times 20 individual tree replicates) [z] | | | |
|---|---|---|---|---|
| Treatment | Gray pulp (scale 1-4) | Vascularization (scale 1-4) | Decay (scale 1-4) | Days to ripen (days) |
| July + August N | 0.9 | 0.53 a | 0.4 | 11.1 a |
| July + August NPK | 1.2 | 0.24 b | 0.7 | 9.9 ab |
| November N | 0.9 | 0.47 ab | 0.6 | 10.4 ab |
| November NPK | 1.0 | 0.28 ab | 0.6 | 11.3 a |
| April N | 0.8 | 0.34 ab | 0.4 | 9.9 ab |
| April NPK | 0.8 | 0.21 b | 0.5 | 9.6 b |
| BMP N | 0.8 | 0.25 b | 0.3 | 10.4 ab |
| BMP NPK | 0.8 | 0.37 ab | 0.5 | 10.6 ab |
| *P*-value | 0.7776 | 0.0654 | 0.8252 | 0.0914 |

[z]Means in a vertical column followed by a different letter are different at *P*=0.05 by Duncan's Multiple Range Test.

less) than fruit from trees receiving the low rate of N as a split application in July and August and fruit from trees receiving a double dose of NPK in November (*P*=0.0914) (Table 4). Fruit from all other treatments took an intermediate number of days to ripen that was not significantly different from the above treatments. It is interesting that fruit harvested in 2005 took only one more day to ripen than fruit harvested in 2004.

It is too early in the research to draw any conclusions. Due to alternate bearing, fertilization research with tree crops must be continued for a minimum of three years to have at least one replication of an on- or off-crop year. It is preferable to conduct such research for at least four years to have two complete cycles of on- and off-crops. This is especially true for 'Hass' avocado orchards in California, which have an alternate bearing index [ABI = (Year 1 yield - Year 2 yield) ÷ (Year 1 yield + Year 2 yield)] ranging from 0.57 to 0.92 (Lovatt, 1997). An ABI equaling zero means that alternate bearing is absent; an ABI of one means there is no crop following and an on-crop. Thus, in California, 'Hass' orchards on average undergo a 60% to 90% reduction in yield following an on-crop.

With this in mind, the results obtained this year for trees receiving the low rate of NPK as a split application in July and August must be examined in light of last year's results since these trees received their full fertilization treatment last year. Last year trees receiving the low rate of NPK as a split application in July and August yielded significantly more large size fruit (packing carton sizes 60+48+40 and fruit of packing carton sizes 60 through 32) per tree (P £ 0.10) and had numerically, but not significantly, more total yield per tree than trees receiving only N as a split application in July and August, trees receiving the BMP NPK treatment, and trees receiving a double dose of NPK in November. Thus, the relatively negative yield results observed in the 2005 harvest for trees receiving the low rate of NPK as a split application in July and August in large part likely reflects the effect of the greater overall yield and greater yield of large size fruit obtained for this treatment in the 2004 harvest.

Conversely, it is interesting to note that trees that received a double dose of N in April have the highest 2-year cumulative total yield per tree and highest cumulative yield per tree of commercially valuable large size fruit (combined pool of packing carton sizes 60 through 32), having had higher yields last year and the highest yields this year in the these two categories. This result is consistent with the fact that the double dose of N in April is a treatment that has proven to be one of the best of two treatments identified in two previous studies, a treatment that significantly increased total yield, increased the yield of commercially valuable large size fruit (packing carton size 60+48+40), and reduced the severity of alternate bearing for the four years of the study (P £ 0.05) (Lovatt, 2001). However, additional years of yield data are required to determine the long-term effect of this treatment on yield, fruit size and alternate bearing in this study.

I would like to express my sincere appreciation to Mr. John Grether. Without special individuals like Mr. Grether, who make their orchards available for the type of research reported herein, FREP-funded projects would not be possible. This is Mr. Grether's second such project with me and I am extremely grateful.

# EXPLORING AGROTECHNICAL AND GENETIC APPROACHES TO INCREASE THE EFFICIENCY OF ZINC RECOVERY IN PEACH AND PISTACHIO ORCHARDS

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## INTRODUCTION

Zinc (Zn) is an essential plant micronutrient, and Zn deficiency is widespread, causing economic losses throughout the world. Among fruit crops, pecan, peach, citrus and avocado seem to be particularly sensitive to this disorder. Zinc is the most widely limiting micronutrient for tree fruit production in California, and deficiencies are worse in sandy and alkaline soils. Inadequate zinc availability in soils and limited responses to soil applications of fertilizer zinc has resulted in the large-scale adoption of foliar applications. Recent studies suggest that foliar-applied zinc remains in or on treated leaves and is not transported to other plant parts. As a result, zinc accumulates in the soil because much of the foliar-applied Zn is carried to the orchard floor in leaf litter following leaf fall.

Multiple approaches are proposed to increase the efficiency of fertilizer zinc recovery following both soil and foliar applications. The first approach is to modify soil pH in small areas of the root system to increase soil zinc availability. A second approach is to use cover crops efficient at mobilizing soil Zn, thus making it more available to the trees. The third approach rests upon preliminary data suggesting that other Prunus rootstocks may be more efficient soil zinc scavengers than "Nemaguard," the rootstock currently in use for most peach and nectarine orchards. Finally, we will use labeled zinc ($^{68}$Zn) and tree excavations to study the efficiency of zinc uptake and its distribution throughout the tree from a fall foliar application.

## OBJECTIVES

1. Assess the feasibility of alternative zinc application methodologies to increase the efficiency of zinc recovery by using soil applications to acidify and stimulate root proliferation in a limited portion of the soil volume.
2. Evaluate the potential of using zinc-efficient cover crops to mobilize soil zinc and make it more available to tree roots.
3. Evaluate an experimental peach rootstock that appears to have greater capacity for zinc uptake from soil than rootstocks currently in commercial usage.
4. Compare the efficiency of zinc uptake into the woody tissues of peach trees before, during and after leaf abscission in the fall.
5. Evaluate the distribution of zinc throughout young peach trees (especially to the roots) from a fall foliar application.

## RESULTS AND DISCUSSION

This project was started in 2005 so there are few conclusions to report thus far. Many individual experiments were initiated and some preliminary results have been obtained. Most of the experiments will continue for several years. Below is a brief summary of each set of experiments.

### *Soil Acidification*

A technique developed in Germany called CULTAN (Controlled Uptake Long Term Ammonium Nutrition) has been used successfully to treat Fe and Zn deficiencies in crop plants. The idea is to add Fe or Zn, together with ammonium fertilizer (to stimulate root growth), to a small acidified portion of the soil. This increases the uptake of these metals since they are much more available at lower pH. We tried the technique with some mature peach trees by adding soil sulfur, urea and varying rates of zinc sulfate to an 18" deep hole near the tree. Leaf samples several months later showed higher zinc levels with high rates of zinc sulfate. Over time, we hope to see increased leaf zinc with the lower zinc sulfate rates as well.

To newly planted peach trees we tried a modification of this approach. Within each planting hole we added a "root bag" containing 100g urea, 100g sulfur and 0, 10 or 50g zinc sulfate. Each bag was wrapped with cheesecloth for easy handling. Leaf samples were taken in mid-summer but have not yet been analyzed.

### *Companion Crops*

Barley and other graminaceous species are very efficient at taking up Zn and Fe under conditions where these metals are low in the soil. They do this by releasing molecules called phytosiderophores that help extract these nutrients from the soil. When another crop is planted with the barley, its Zn and Fe uptake can also be improved if its roots are in close proximity to the barley roots. On our first attempt we planted winter barley in the rows next to some 3-year-old peach trees, but could not measure any increase in leaf Zn. We felt it was probably because the roots of the two species were not close enough together. This year we will plant the barley right under the tree to maximize root interaction.

We have also obtained seed from a barley variety that is reported to be even more zinc-efficient than normal varieties. It is not commercially grown in the USA so only a small amount was available. A preliminary trial will be conducted around a few trees to see if it stimulates zinc uptake better than standard varieties.

### *Rootstocks*

Rootstocks can have a very substantial effect on the uptake of nutrients in fruit trees. We have a 3-year-old peach orchard at the Kearney Ag Center planted on four different rootstocks. The trees have never been fertilized with zinc in any form. One of these rootstocks, Hiawatha, has considerably more zinc in the leaves, and especially in dormant shoots, compared to the standard rootstock Nemaguard (Table 1). The three rootstocks other than Hiawatha would all be considered Zn-deficient based on the current recommendations for mid-summer leaf samples. They have all shown some degree of zinc-deficiency symptoms. This raises the possibility of completely eliminating zinc sprays with certain rootstocks. These data also suggest that it may be possible to store large amounts of zinc in the dormant wood. Perhaps such trees would not need to be fertilized with zinc for at least several years. We have some trees in the sand tank experiment (see our other FREP report), which have zinc concentrations in dormant shoots as high as 75 ppm. We will monitor these trees carefully to see how efficiently the zinc is recycled and supplied to growing shoots and fruits over several years. We will also be investigating methods, other than rootstocks, of substantially elevating the zinc levels in dormant tissues.

**Table 1. Zinc concentrations in leaves (July 2004) and dormant shoots (January 2005) of O'Henry and Springcrest peach trees as influenced by four different rootstocks. The two cultivars are combined, as there were no differences between them.**

| Tissue | Rootstock | | | |
|---|---|---|---|---|
| Sampled | Nemaguard | Controller 9 | Controller 5 | Hiawatha |
| Leaves (7/04) | 10.9 bc | 11.9 b | 9.4 c | 21.6 a |
| Shoots (1/05) | 25.8 b | 28.4 b | 18.9 c | 90.3 a |

### *ZN68 Studies*

The stable isotope Zn68 has proved to be a valuable tool for addressing many questions regarding zinc uptake efficiency and distribution in the tree. In one experiment, we have been able to show about 7% of the zinc applied to peach leaves in late fall is taken into the perennial parts of the trees before leaf fall. Of the amount taken up, nearly half is transported to the roots, but is then remobilized in the spring and mostly ends up in new growth. This suggests zinc is much more mobile than we originally thought. We have a series of experiments planned to further study the distribution of zinc throughout the tree and test several approaches (rates, timing, additives, etc.) of increasing the amount of zinc that ends up in the tree from foliar applications.

## CONCLUSION

Although this project has just begun, we already have promising leads on several approaches to increasing the efficiency of zinc applications to fruit and nut trees. Over the next two years we hope to better understand aspects of zinc uptake, movement, and storage in the tree and focus on the most efficient and environmentally sound way to supply this nutrient to the plant.

# Reevaluating tissue analysis as a management tool for lettuce and cauliflower

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## Introduction

Plant tissue analysis is an established practice in the commercial vegetable industry. Both petiole analysis for unassimilated nutrients ($NO_3$-N, $PO_4$-P, and K) and whole leaf analysis for total nutrient concentration are common. Tissue testing has been widely advocated as a fertilizer 'best management practice.' However, in recent years a number of studies have cast doubt about the validity of commonly suggested nutrient 'sufficiency' levels, or even whether tissue testing is a useful management practice. Collectively, these studies found a) poor correlation between tissue nutrient concentration and concurrently measured soil nutrient availability, b) a high degree of variability in tissue nutrient concentration in adequately fertilized crops from different fields, and c) unrealistically high nutrient 'sufficiency' standards for several crops. These findings call into question the practical value of tissue analysis and interpretation as currently performed. Commercial use of a flawed technique could result in excessive fertilization in some fields, and possibly yield loss in others. This project proposed a comprehensive review of tissue analysis for two important cool-season vegetables (lettuce and cauliflower) to revise currently suggested sufficiency levels, quantify the effects of potentially confounding environmental factors, and reevaluate sampling and handling techniques.

## Objectives

1. Develop broadly applicable optimum tissue macro- and micronutrient concentration ranges for lettuce and cauliflower.
2. Quantify the sources of variability in tissue sampling and handling to standardize practices and improve interpretation of results.
3. Document the correlation (or lack thereof) between soil nutrient availability and tissue nutrient level.

## Methods

A survey of more than 100 commercial fields was conducted from spring 2004 through fall 2005 in the Salinas and Santa Maria production areas. The fields were divided among head lettuce, romaine lettuce, and cauliflower. Fields were chosen to cover the production season from early spring through fall, with fields scattered from near the coast (low $ET_o$ environment) to higher $ET_o$ environments farther inland. Fields were sampled at three growth stages: 1) early vegetative growth; 2) midseason (early heading stage for lettuce, early button formation for cauliflower); and 3) within a week of harvest. In each field and at each growth stage a composite sample of soil, of whole leaves, and of midribs was collected. Table 1 describes the analyses performed.

**Table 1. Soil and plant sampling protocol.**

| Sample type | Growth stage | Analyses |
|---|---|---|
| soil | early | texture; pH; organic matter; Olsen P; mineral N; exchangeable K, Ca, Mg, Na; DTPA extractable Zn, Mn, Fe, Cu; saturated paste B |
| | mid | mineral N |
| | pre-harvest | mineral N |
| whole leaves | all | total N, P, K, Ca, Mg, S, Zn, Mn, Mo, Cu, Fe, B, Na, Cl |
| midribs | all | $NO^{-3}N$, $PO^{4}$-P, K |

Participating growers provided the following information: variety, planting and harvesting dates, seasonal fertilizer rates, and the commercial yield of the field. Growers also rated crop quality (good / fair / poor) and noted any field in which the yield did not reflect the productivity of the crop (poor market conditions, serious disease or insect damage, etc.) so those fields could be dropped from the data set.

When all laboratory analysis is complete we will use the Diagnosis and Recommendation Integrated System (DRIS) to evaluate this data set. DRIS is a mathematical framework that compares nutrient concentration differences between high- and low-yield crops. In the DRIS approach, differences in tissue nutrient concentrations and nutrient ratios between low- and high-yield fields are used to estimate the degree to which various nutrients may limit yield, either due to deficiency or excess. For each nutrient, a DRIS-derived, growth stage-specific optimum tissue nutrient concentration range will be developed. These optimum ranges should be more widely applicable than current tissue concentration guidelines, which in most cases were empirically derived from just a few fertilizer trials. They will also be the first systematically developed micronutrient guidelines available for these crops in California; given the similarities among vegetable crops in micronutrient sufficiency standards developed elsewhere, these optimum ranges should be applicable to salad crops other than lettuce and cauliflower. The comprehensive information gathered from survey fields will also be useful in determining the accuracy of soil tests to predict crop P, K, and micronutrient sufficiency. The correlation between tissue N status and concurrently measured soil N availability will show conclusively whether tissue analysis can provide any guidance on additional sidedress N requirement, or on seasonal N fertilization efficiency.

## Results

Soil and tissue sampling has been completed, but laboratory analysis of the 2005 samples is ongoing. Until that analysis is complete the development of the final DRIS norms cannot be undertaken. However, using the 2004 data it is possible to calculate the 'typical' nutrient concentration ranges from good quality, high-yield fields. Of the fields sampled in 2004, 25 head lettuce, 13 romaine, and 21 cauliflower fields were rated as 'good production and quality.' Using only those 'good' fields, the mean and standard deviation

**Table 2. Typical macronutrient concentration ranges for fields of high yield and good quality.**

| | | % in whole leaf | | | PPM in midrib | | % K |
|---|---|---|---|---|---|---|---|
| Crop | Stage | N | P | K | $NO_3$-N | $PO_4$-P | in midrib |
| Head lettuce | 1 | 4.6 - 5.9 | 0.40 - 0.60 | 3.9 - 6.9 | | | |
| | 2 | 4.4 - 5.3 | 0.48 - 0.69 | 3.5 - 5.5 | 4,000 - 10,000 | 2,000 - 3,400 | 5.3 - 7.9 |
| | 3 | 2.8 - 4.2 | 0.32 - 0.51 | 3.3 - 6.4 | 7,000 - 15,000 | 2,700 - 5,200 | 5.5 - 9.6 |
| *Sufficiency reference:* | | | | | | | |
| *#1* | 2 | 3.0 - 4.0 | 0.40 - 0.85 | 3.0 - 4.0 | 6,000 - 10,000 | 3,000 - 4,000 | 4.5 - 7.5 |
| *#2* | 2 | 2.5 - 4.0 | 0.40 - 0.60 | 4.5 - 8.0 | | | |
| *#3* | 3 | 3.8 - 5.0 | 0.45 - 0.60 | 6.6 - 9.0 | | | |
| Romaine | 1 | 4.2 - 5.8 | 0.45 - 0.73 | 3.9 - 6.9 | | | |
| | 2 | 3.9 - 5.2 | 0.49 - 0.77 | 3.8 - 6.2 | 2,900 - 9,300 | 1,700 - 3,500 | 5.1 - 7.2 |
| | 3 | 3.2 - 4.6 | 0.47 - 0.73 | 3.4 - 7.1 | 4,200 - 9,000 | 1,900 - 3,900 | 4.8 - 7.9 |
| *Sufficiency reference:* | | | | | | | |
| *#2* | 3 | 3.5 - 4.5 | 0.35 - 0.60 | 5.0 - 6.0 | | | |
| *#3* | 3 | 3.5 - 4.5 | 0.45 - 0.80 | 5.5 - 6.2 | | | |
| Cauliflower | 1 | 5.2 - 6.4 | 0.43 - 0.71 | 2.3 - 3.4 | | | |
| | 2 | 4.3 - 7.1 | 0.50 - 0.93 | 2.1 - 3.9 | 6,000 - 15,000 | 3,300 - 4,900 | 3.5 - 5.5 |
| | 3 | 3.8 - 5.9 | 0.50 - 0.89 | 2.1 - 4.1 | 3,000 - 11,000 | 3,300 - 5,800 | 3.2 - 4.3 |
| *Sufficiency reference:* | | | | | | | |
| *#1* | 2 | 3.0 - 5.0 | 0.50 - 0.70 | 2.6 - 4.1 | 6,000 - 12,000 | 3,500 - 5,000 | 4.0 - 6.0 |
| *#2* | 2 | 3.0 - 5.0 | 0.40 - 0.70 | 2.0 - 4.0 | | | |
| *#3* | 2 | 3.3 - 4.5 | 0.33 - 0.80 | 2.6 - 4.2 | | | |

Sufficiency references: 1) Western Fertilizer Handbook; 2) University of Florida Publication SS-VEC-42; 3) Plant Analysis Handbook

**Table 3. Typical micronutrient concentration ranges for fields of high yield and good quality.**

| Crop | Stage | % Ca | % Mg | % S | PPM Zn | PPM Mn | PPM Fe | PPM Cu | PPM B | PPM Mo |
|---|---|---|---|---|---|---|---|---|---|---|
| Head lettuce | 1 | 0.9 - 1.3 | 0.40 - 0.60 | 0.30 - 0.40 | 20 - 80 | 40 - 100 | 210 - 750 | 6 - 11 | 15 - 24 | 0.50 - 1.40 |
| | 2 | 0.4 - 0.7 | 0.20 - 0.40 | 0.25 - 0.35 | 25 - 95 | 30 - 70 | 80 - 260 | 5 - 10 | 16 - 27 | 0.30 - 0.70 |
| | 3 | 0.7 - 1.1 | 0.30 - 0.50 | 0.20 - 0.30 | 25 - 65 | 35 - 100 | 120 - 250 | 3 - 8 | 24 - 35 | 0.25 - 0.60 |
| *Sufficiency reference:* | | | | | | | | | | |
| *#2* | 2 | 1.4 - 2.0 | 0.30 - 0.70 | > 0.30 | 25 - 50 | 20 - 40 | 50 - 150 | 5 - 10 | 15 - 30 | |
| *#3* | 3 | 1.5 - 2.3 | 0.36 - 0.50 | | 25 - 250 | 25 - 250 | 50 - 100 | 7 - 25 | 23 - 50 | |
| Romaine | 1 | 0.9 - 1.3 | 0.40 - 0.60 | 0.30 - 0.40 | 20 - 75 | 45 - 95 | 180 - 700 | 5 - 10 | 17 - 26 | 0.20 - 1.40 |
| | 2 | 0.4 - 0.8 | 0.20 - 0.40 | 0.25 - 0.35 | 25 - 70 | 40 - 80 | 85 - 220 | 5 - 8 | 17 - 32 | 0.20 - 0.60 |
| | 3 | 0.6 - 1.0 | 0.25 - 0.40 | 0.25 - 0.35 | 30 - 70 | 40 - 80 | 85 - 300 | 4 - 9 | 23 - 36 | 0.20 - 0.50 |
| *Sufficiency reference:* | | | | | | | | | | |
| *#2* | 3 | 2.0 - 3.0 | 0.25 - 0.35 | | 20 - 50 | 15 - 25 | | 5 - 10 | 30 - 45 | 0.10 - 0.40 |
| *#3* | 3 | 2.0 - 2.8 | 0.60 - 0.80 | | 20 - 250 | 11 - 250 | 40 - 100 | 5 - 20 | 25 - 60 | |
| Cauliflower | 1 | 1.6 - 3.5 | 0.40 - 0.80 | 0.70 - 1.50 | 28 - 60 | 35 - 65 | 60 - 310 | 4 - 9 | 16 - 31 | 0.40 - 1.20 |
| | 2 | 0.8 - 2.8 | 0.20 - 0.60 | 0.85 - 1.25 | 32 - 70 | 25 - 55 | 100 - 160 | 4 - 8 | 23 - 31 | 0.60 - 1.60 |
| | 3 | 0.6 - 2.9 | 0.25 - 0.55 | 0.90 - 1.20 | 33 - 66 | 25 - 65 | 60 - 260 | 4 - 6 | 24 - 32 | 0.40 - 1.60 |
| *Sufficiency reference:* | | | | | | | | | | |
| *#2* | 2 | 0.8 - 2.0 | 0.25 - 0.60 | 0.60 - 1.00 | 30 - 50 | 30 - 80 | 30 - 60 | 5 - 10 | 30 - 50 | |
| *#3* | 2 | 2.0 - 3.5 | 0.27 - 0.50 | | 20 - 250 | 25 - 250 | 30 - 200 | 4 - 15 | 30 - 100 | 0.50 - 0.80 |

Sufficiency references: 2) University of Florida Publication SS-VEC-42; 3) Plant Analysis Handbook

**Table 4. Soil physiochemical and fertility characteristics of 2004 survey fields.**

| | pH | Organic matter (%) | Olsen P (PPM) | Exchangeable K K (PPM) | Exchangeable cations (meq/100 g) Ca | Mg | Na | DTPA extractable micronutrients (PPM) Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 7.4 | 1.60 | 66 | 294 | 15.7 | 4.5 | 0.7 | 2.9 | 16.2 | 17.9 | 2.8 |
| Maximum | 8.0 | 4.50 | 141 | 1180 | 38.8 | 15.9 | 4.6 | 10.6 | 53.8 | 51.3 | 11.6 |
| Minimum | 6.7 | 0.60 | 19 | 87 | 5.6 | 1.5 | 0.1 | 0.5 | 3.5 | 5.4 | 0.5 |
| Agronomic threshold | | | 50 | > 120 | | | | 0.5 | | 5 | |

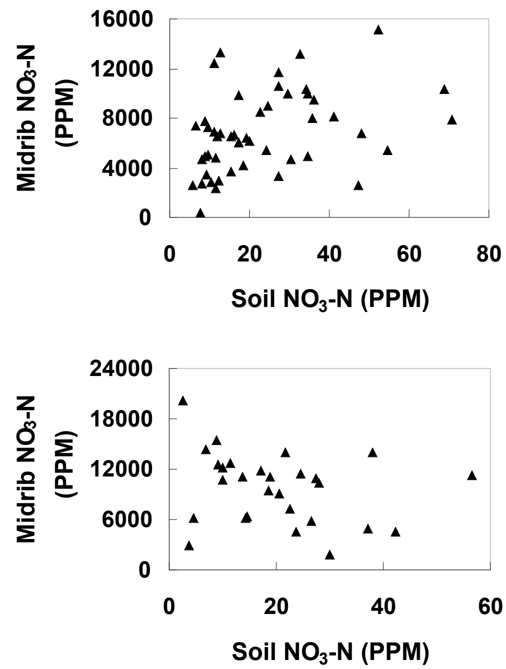
for all nutrients were calculated. Tables 2 and 3 list the 'typical' tissue nutrient concentration ranges for these 'good' fields, each range defined as one standard deviation around the mean value; statistically, approximately 65% of all 'good' fields would be expected to fall within these ranges. Tissue nutrient concentrations within these ranges would be assumed to be adequate for successful production. For comparison, nutrient sufficiency values from several widely used reference sources are also given.

A number of observations can be made from these tables. Head lettuce and romaine have very similar whole leaf macronutrient concentration ranges; however, romaine appeared to have lower midrib $NO_3$-N and $PO_4$-P values. Compared to lettuce, cauliflower had marginally higher whole leaf N and P, and substantially lower K. These typical nutrient concentration ranges from our 2004 sampling differed considerably for some nutrients and some growth stages from the sufficiency ranges given in the reference publications. The two most obvious differences are the relatively low whole leaf K, and low midrib $NO_3$-N and $PO_4$-P, that we found for lettuce. Regarding micronutrients, the most obvious difference between the reference sufficiency ranges and the values from our survey was for calcium; for lettuce the high end of our 'typical' range was below the low threshold value of both references. For all other micronutrients our ranges fell close to the reference values.

Soil analysis of the 2004 fields (Table 4) revealed a wide range of physiochemical and nutrient characteristics. Soil micronutrient supply was plentiful in most fields; with only the lowest fields approaching established agronomic threshold values for Zn and Fe. The long-term effect of vegetable crop fertilization was evident in soil P and K values. Native soil levels of Olsen P and exchangeable K in coastal soils prior to agricultural use would have typically been in the range of 10-20 and 80-400 PPM, respectively, depending on geological origin and soil texture. The very high P and K levels now observed in some fields suggest that many growers continue to ignore soil testing in the formulation of their fertility plans. Some fields with Olsen P > 100 PPM (twice the agronomic threshold for lettuce) were fertilized with P for the survey crop; some fields with K > 800 PPM (at least 5 times the agronomic threshold for lettuce) were still receiving K fertilization. This not only represents a waste of money, but with regard to P also represents a water quality hazard.

While tissue nutrient monitoring can detect potentially yield-limiting nutrient deficiencies, the value of tissue testing as a fertilizer management technique is questionable. Fig. 1 shows the relationship of midrib $NO_3$-N concentration and concurrently measured soil $NO_3$-N (top foot depth) at midseason sampling. Over a wide range of soil $NO_3$-N concentration there was no useful correlation with midrib $NO_3$-N values for either crop. This suggests that the tissue test provided no useful information about the current level of soil $NO_3$-N availability, and therefore provided no guidance regarding the need for additional N fertilization.

**Fig. 1. Relationship between midseason midrib $NO^3$-N in lettuce (top) and cauliflower (bottom) and concurrently measured soil $NO^3$-N.**



# Developing starter fertilizer recommendations for California rice growers

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## Introduction

In 1991, the California Rice Straw Burning Reduction Act (AB1378) attempted to mitigate the negative impact of rice straw burning on air quality by requiring rice farmers to adopt alternative methods of straw disposal for the more than 500,000 acres of rice grown in the Sacramento Valley. Despite initial uncertainty over the impact of straw incorporation on rice growth and yield, in-field residue incorporation has transitioned from a burning "alternative" to the primary means of residue management. As a result, the amount of organic matter in the soil has increased and nutrient availability has been altered. From long-term experiments, it is clear that available soil N is increased after three years of residue incorporation and winter flooding (Eagle et al., 2000); however, the impact on soil fertility in growers' fields, where management options are frequently rotated to reduce pest and weed pressure, is uncertain.

Survey results indicate that 29% of growers reported reducing fertilizer applications in fields where they regularly incorporated residues, while 9% of growers increased fertilizer rates and 52% reported no change following legislated reductions in burning.[1] Given the reported lack of a clear consensus on the impact of straw management on soil fertility and fertilizer practices, it is not surprising that there is a perceived need among growers for improved fertility management guidelines. In an effort to address that need, we began a comprehensive evaluation of the impact of rice straw incorporation on nutrient cycling and fertility management by rice growers throughout the Sacramento Valley in 2003. The research included fertility trials conducted with 15 growers in 38 fields, self-reporting, extensive soil and plant sampling, and monitoring of three different N rates across a variety of soils, under different management practices.[2] When three-year field histories provided by the growers were used to group the data for analysis, a comparison of relative yields within fields indicated that those fields with a history of residue incorporation had significantly greater yields under the reduced fertilizer treatment than those where residue was consistently burnt or baled (P=0.03), reaffirming that changes in straw management have altered nutrient availability. Furthermore, greater than 50% of those fields studied in 2003 were P-deficient according to current soil fertility guidelines, though less than 5% exhibited leaf tissue concentrations below the critical level at maximum tillering (<1000ppm) suggesting that either the soil or tissue guidelines should be reevaluated.

With the assistance of CDFA/FREP, we are continuing trials in grower managed fields and expand the scope of the trials to include sites where more complete fertilizer timing, material and rate response trials will occur. The specific objectives are: 1) To evaluate current starter fertilizer recommendations for flooded rice soils; 2) To improve critical N, P and K guidelines for mid-season tissue.

[1]A summary of the results is available on the UCCE Rice web page: http://agronomy.ucdavis.edu/uccerice
[2]All rate manipulations were made to pre-plant fertilizer applications. The N rates were based upon grower standard practice for a given field, and included a 25% or 25 lb N ac-1 decrease in pre-plant N, standard practice, and a 25 % or 25 lb N ac-1 increase in pre-plant N.

## Objectives (Tasks)

1. To evaluate current starter fertilizer recommendations for flooded rice soils
2. To improve critical N, P and K guidelines for mid-season tissue.

## Methods

In 2005, replicated experiments were set up in five growers' fields representing soil and management practices common to California rice production (Table 1). At all sites a medium grain Japonica-type rice is being grown.

**Table 1. Site location and details for each field in the study.**

| County | Nearest town | Previous years straw mgmt | Planting date | Current NPK rate (lb/ac) | Early season water mgmt. |
|---|---|---|---|---|---|
| Colusa | Arbuckle | Straw incorp past 2 yr. Tomato before | May 1 | 100 lb/ac aqua-N; 150 lb urea surface applied before planting | Leathers method |
| Yuba | Sheridan | Straw incorp/roll since 1996 | May 6 | 132 of aqua-N 300 of 7-20-20 | Drained May 24 for clincher. Re-flooded around June 11-15 |
| Colusa | Princeton | Straw incorporated for past 3 yr | May 11 | 142 lb N/ac of aqua-N 200 of 16-20-0 | Perm. flood |
| Butte | Gridley | Straw incorporated for past 10 yr | May 26 | 95 of aqua-N 250 lb of 12:15:23 | Perm. flood |
| Butte | Richvale | Straw incorporated for past 15 yr | June 3 | 105 of aqua N ??? after flooding | Perm flood |

Eight treatments were used to evaluate crop response to, and efficiency of, N, P and K starter fertilizers (Table 2). Treatments (Table 2) were set up in a randomized complete block design at each site, with each site having five replications. Efforts were made to have each replication in different checks; however, at two locations (both in Butte county) all replications had to be in a single check to facilitate farmer field operations. The two growers in Butte County applied starter fertilizer by air requiring us to have all five blocks in a single check.

**Table 2. Treatments and design**

| Treatment # | Basal Aqua N | Starter Fertilizer | Plot type | $^{15}N$ plot included as part of main trt |
|---|---|---|---|---|
| 1 | 0 | -PK | Main | |
| 2 | Yes | --- | Main | |
| 3 | Yes | N-- | Inside #2 | Yes |
| 4 | 0 | NPK | Inside #1 | |
| 5 | Yes | NPK | Main | Yes |
| 6 | Yes | -PK | Main | |
| 7 | Yes | N-K | Main | |
| 8 | Yes | NP- | Main | |

Starter fertilizer rates will be: N (30), $P_2O_5$ (50), $K_2O$ (50). Aqua-N will be as per grower. Sources: N (ammonium sulfate), P (TSP) and K (Potassium sulfate)

Plot size varied by site to account for differences in equipment width (fertilizer applicators and harvesters). Plot length ranged from 125 ft to 200 ft. A single replication showing the layout of the eight treatments is shown in Figure 1. Treatment details are shown in Table 2. The rational for the treatments are as follows:

- TRT 5-8 is a simple nutrient omission trial to identify what nutrients are limiting. Nutrient limitations will be determined on the basis of plant biomass and yield.
- TRT 1 is a control and gives us the indigenous N supply. From this we can measure the benefit (and efficiency) of fertilizer N of the other treatments.
- TRT 2 is a control. We can use this to measure fertilizer use efficiency of starter fertilizer (by mass balance).
- When the growth and N uptake curves of 1 and 2 and of 4 and 5 diverge, this will determine when the crop under starter and no starter has reached the aqua-N.
- Treatment 5 with the $^{15}N$, we will be able to determine the contribution of the starter to the total N uptake as well as determine N use efficiency. Comparison of this with the $^{15}N$ in treatment 3 will indicate if P and K improve N use efficiency.

Every effort was made to apply the starter fertilizer as the farmer would. In all cases it was surface applied.

Soils were sampled from each replication after the fields were planed. These were dried and processed in preparation for analysis. At three and four weeks after sowing, whole plant samples were taken from treatments 1, 2, 4, 5 and 6. These plants were analyzed for aboveground biomass and nutrient content. Data from these samples will be used for the determination of starter N fertilizer uptake efficiency. Five weeks after sowing (mid-tillering): (1) plant samples were taken for aboveground biomass from all treatments, (2) soil and plant samples were taken from the $^{15}N$ plots, and (3) the most recently expanded leaf from 20 plants in each plot was taken for tissue analysis. At harvest, crop cuts were taken from each treatment to determine biomass. From the $^{15}N$ plots soils and plant samples were taken to determine N use efficiency.

## Results and Conclusions

At the time of writing this report, plant and soil samples had not been analyzed and no data from the harvest sample was available. These results are preliminary results (Table 3) based on early season biomass production measured at three, four, and five (mid-tillering) weeks after planting indicate that:

(1) At all sites there was a benefit to applying a complete starter (N, P and K) application. Early season aboveground biomass was significantly higher when there was an NPK starter application than when no starter fertilizer was applied.

(2) At all sites there were benefits to the application of starter N. Where starter N was applied, biomass was higher at all sites and sample times. This is despite a wide range of early season water management practices for seed establishment (water drained for seed establishment-Leathers method) and weed control (one site dried down soil for *"Clincher"* application and three sites had soils permanently flooded).

(3) The early season biomass data indicate that the crop begins taking up aqua-N sometime before three weeks after planting, despite aqua-N being injected four inches deep. However, even though young rice seedlings are able to take up aqua-N very early, there was still a positive benefit of applying starter N near the surface.

(4) Early season P and K deficiencies were measured at some sites but it is unclear if yields will be affected.

**Table 3. Aboveground biomass measured at approximately 3, 4 and 5 weeks after sowing (DAS) at each farmer site.**

**Colusa-Arbuckle**

| Treatment | | | Aboveground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (22 DAS)** | **T2 (30 DAS)** | **T3 (37 DAS)** |
| 1 | 0 | -PK | 30 b | 95 c | 212 d |
| 2 | Yes | --- | 30 b | 112 bc | 306 c |
| 3 | Yes | N-- | | | 453 a |
| 4 | 0 | NPK | 36 a | 156 a | 379 b |
| 5 | Yes | NPK | 35 a | 172 a | 442 a |
| 6 | Yes | -PK | 33 ab | 124 b | 368 bc |
| 7 | Yes | N-K | | | 412 ab |
| 8 | Yes | NP- | | | 456 a |
| **ANOVA (P)** | | | **0.0508** | **0.0000** | **0.0000** |

**Yuba-Sheridan**

| Treatment | | | Aboveground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (26 DAS)** | **T2 (31 DAS)** | **T3 (38 DAS)** |
| 1 | 0 | -PK | 190 c | 418 c | 546 f |
| 2 | Yes | --- | 212 bc | 499 b | 703 de |
| 3 | Yes | N-- | | | 901 ab |
| 4 | 0 | NPK | 249 a | 530 ab | 675 e |
| 5 | Yes | NPK | 249 a | 580 a | 959 a |
| 6 | Yes | -PK | 226 a | 475 b | 709 cde |
| 7 | Yes | N-K | | | 819 bc |
| 8 | Yes | NP- | | | 759 bcd |
| **ANOVA (P)** | | | **0.0037** | **0.0002** | **0.0000** |

**Colusa-Princeton**

| Treatment | | | Aboveground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (22 DAS)** | **T2 (29 DAS)** | **T3 (35 DAS)** |
| 1 | 0 | -PK | 119 c | 233 d | 578 e |
| 2 | Yes | --- | 144 b | 315 c | 879 cd |
| 3 | Yes | N-- | | | 1036 ab |
| 4 | 0 | NPK | 190 a | 382 b | 841 d |
| 5 | Yes | NPK | 207 a | 460 a | 1163 a |
| 6 | Yes | -PK | 164 b | 353 bc | 1003 bc |
| 7 | Yes | N-K | | | 1006 bc |
| 8 | Yes | NP- | | | 1116 ab |
| **ANOVA (P)** | | | **0.0000** | **0.0000** | **0.0000** |

**Butte-Gridley**

| Treatment | | | Aboveground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (21 DAS)** | **T2 (27 DAS)** | **T3 (35 DAS)** |
| 1 | 0 | -PK | 136 b | 306 c | 726 d |
| 2 | Yes | --- | 145 b | 287 c | 681 d |
| 3 | Yes | N-- | | | 741 d |
| 4 | 0 | NPK | 159 ab | 368 b | 960 c |
| 5 | Yes | NPK | 187 a | 412 a | 1312 ab |
| 6 | Yes | -PK | 182 a | 410 a | 1249 b |
| 7 | Yes | N-K | | | 760 d |
| 8 | Yes | NP- | | | 1424 a |
| **ANOVA (P)** | | | **0.0071** | **0.0000** | **0.0000** |

**Butte-Richvale**

| Treatment | | | Aboveground biomass (kg ha $^{-1}$) | | |
|---|---|---|---|---|---|
| **#** | **Basal Aqua N** | **Starter Fertilizer** | **T1 (20 DAS)** | **T2 (26 DAS)** | **T3 (33 DAS)** |
| 1 | 0 | -PK | 69 c | 215 c | 578 e |
| 2 | Yes | --- | 75 bc | 293 b | 915 cd |
| 3 | Yes | N-- | | | 988 bcd |
| 4 | 0 | NPK | 82 ab | 306 b | 871 d |
| 5 | Yes | NPK | 87 a | 345 a | 1148 ab |
| 6 | Yes | -PK | 76 bc | 289 b | 916 cd |
| 7 | Yes | N-K | | | 1098 abc |
| 8 | Yes | NP- | | | 1206 a |
| **ANOVA (P)** | | | **0.0093** | **0.0000** | **0.0001** |

# Improving Water-Run Nitrogen Fertilizer Practices in Furrow- and Border Check-Irrigated Field Crops

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## Introduction

Injection of N fertilizers in furrow and border check-irrigation systems is a common practice in California and elsewhere in the western U.S. It is a convenient, low-labor requiring method of application, and in mid to late season, it is the only practical method for applying N to most row crops, except for the small acreage irrigated by drip systems. In furrow and border check systems, low-cost anhydrous and aqua ammonia can be used, whereas it is not feasible to use these materials in drip (high potential to create precipitates and emitter plugging) or sprinkler (very high loss of N by volatilization) systems.

The main limitation of fertigation in furrow and border check systems is the potential for non-uniform nutrient application, possibly leading to N deficiencies in some parts of the field, and excessive N and nitrate leaching losses in other parts of the field. Two factors can contribute to this non-uniformity: (1) non-uniform irrigation water application, i.e., poor distribution uniformity; and (2) where the source of N is anhydrous or aqua ammonia, loss of N by ammonia volatilization.

Surprisingly, little research has been conducted on the conditions and management practices that influence spatial distribution of water-run N fertilizers in these systems. The few studies that have been conducted are in disagreement on the severity of the problem and the role of ammonia volatilization. Some researchers have reported that when irrigation water was properly controlled in furrows, water-applied ammonium concentrations varied within 5% between the head and end of the furrows. In a 2003 UC study of dairy lagoon water applied in a furrow system in the San Joaquin Valley, Schwankl et al. observed no change in the ammonium and organic N concentrations of the water sampled along a furrow over a 1250-ft distance, even though the ammonium concentration was relatively high at 100 mg N/L.

Other researchers in Australia and California have measured $NH_4$ concentration drops of 50% from top to bottom of the field. The main factors influencing ammonia loss from water are ammonium concentration, pH, water depth, wind speed, and temperature, and the different results from one experiment to another can probably be accounted for by variations in these factors.

Management practices with the potential to improve surface gravity irrigation distribution uniformity are well known. To the extent that these practices improve water distribution uniformity, they will improve the uniformity of water-run fertilizer. However, none of these practices are attractive to farmers from a financial or logistical standpoint; or they are beneficial only in limited situations.

A practice that does not depend so much on improving the distribution uniformity of water over an entire irrigation set is to delay the injection of fertilizer until the water has advanced some distance down the furrow. This avoids fertilizer application on the upper end of the field during the time of the most rapid infiltration. However, a standard reference on fertigation used by industry in California (Fertigation. Burt et al., 1998. ITRC, San Luis Obispo, CA) recommends against delaying injection of fertilizer or other chemicals in surface gravity irrigation systems. The authors note that properly operated, such systems will generate tailwater containing the fertilizer, which then unavoidably will be applied at the beginning of the next field or irrigation set, thus defeating the tactic of delayed injection.

We believe that adjusting the timing of injection of N fertilizer materials has some potential. In many situations, the limitation noted by Burt et al. will not be a problem. Tailwater is often a small volume of the supply to the next field or block of furrows. Our research has the potential to provide a set of recommendations to growers that, if adopted, will allow them to achieve some improvement in fertilizer N use efficiency with accompanying cost savings and reductions in nitrate leaching.

## Objectives

Objectives of the project are to:

1. Investigate the relationship of timing of water-run fertilizer injection during irrigation events on N application uniformity and determine the role of ammonia volatilization.
2. Develop recommendations for N fertilizer injection timing for soils with different textures or water intake rates.
3. Extend the information developed in the project through presentations at professional meetings, UC Cooperative Extension newsletter articles, and a U.C. peer-reviewed technical bulletin.

## Procedures

We conducted on-farm trials in five commercial cornfields in 2005. A similar set of measurements will be made in 2006. The experiments were conducted when corn plants were small, so that we could see the advancing furrow water. Sample results are shown for two of the sites, one with sandy loam soil, and the other with clay loam soil.

At each site, data was collected from a single furrow during three furrow irrigation sets on consecutive days. The farmers and their fertilizer retailers provided a standard anhydrous ammonia tank with the regulator set to provide 40-60 lb N/acre during the normal irrigation. At both sites reported below, a hose from the tank injected the ammonia into a head ditch at a point 1,000-2,000 ft from our measurement furrows. Irrigation was carried out by farm employees using siphon pipes from the head ditch into the furrows. To carry out the two delayed fertilizer injection treatments, the anhydrous ammonia tank valve was not turned on until water had advanced to about 50% or 75% of the distance across the field. In order to provide the same total amount of N per acre in the considerably shorter time of injection in the delayed treatments, a higher $NH_3$ flow rate was used.

This required us to guess the time that would be required to finish the irrigation on those sets; furthermore, there was some uncertainty in the length of time required for the ammonia to travel in the head ditch from the tank to the furrows where measurements were being made. A field pH meter and an ion-specific $NH_4$ electrode were very helpful in tracking the advance of ammonium in the head ditch and in the furrows.

During each irrigation set, flow rate in the furrows was monitored with a flume placed near the head of the field, and advance times for the water were recorded at 100-ft intervals. At 30- to 60-minute intervals, water samples were collected from points along the furrow. Samples were stored in ice chests and analyzed for ammonium later in the laboratory. Water pH, air temperature, and wind speed were measured in the field.

## YEAR 1 RESULTS

Results from two of the locations with contrasting soil textures are shown here. We have not yet calculated the N application rates achieved. Irrigation distribution uniformities (DU) ranged from 54% to 88% (Table 1). DU is defined as the amount of water applied to the lowest quarter of the area expressed as a percent of the average amount applied to the entire field, which in our fields was the last, or bottom 25% of the furrow. These DU values are calculated for water applied until we stopped taking our measurements, i.e., until shortly after the water reached the end of the field. The farmers' irrigators may have continued the irrigation somewhat longer, and therefore the actual DU values may have been somewhat higher than those shown in Table 1.

**Table 1. Irrigation water applied and distribution uniformity in anhydrous ammonia fertigation experiment.**

| Set/treatment | Average application rate, inch/hr | Time, hr | Average total applied, inches | Distribution uniformity, % |
|---|---|---|---|---|
| Site SJ1 – clay/clay loam | | | | |
| 1 – fert full | 0.61 | 8 | 4.9 | 88 |
| 2 – fert delay 50% | 0.73 | 9 | 6.6 | 59 |
| 3 – fert delay 75% | ND | 8 | -- | -- |
| Site SJ2 – sandy loam/loam | | | | |
| 1 – fert full | 0.80 | 6 | 4.8 | 79 |
| 2 – fert delay 50% | 0.86 | 7 | 6.0 | 54 |
| 3 – fert delay 75% | 0.75 | 6 | 4.5 | 62 |

At all sites and for all three treatments, we observed a substantial decrease in ammonium concentration from the upper to the lower end of the field. The decrease was usually uniform with distance over the length of the field (Fig. 1) and, therefore, we can express it as a percent decrease per 100 ft of furrow distance. The likely explanation for the decrease is ammonia volatilization. Furrow water pH during $NH_3$ fertigation ranged from 9.6 to 10.0 – which indicates a high potential for volatilization. At site SJ1 (clay loam soil), loss as a percent of the source was higher in the delayed injection treatments, which had a higher N concentration – also consistent with ammonia volatilization loss. However, at site SJ2 with sandy loam soil, loss was similar over the range of concentrations used for the three treatments (Table 2).

**Table 2. Initial ammonium concentrations in irrigation water near upper end of field and decrease down furrow.**

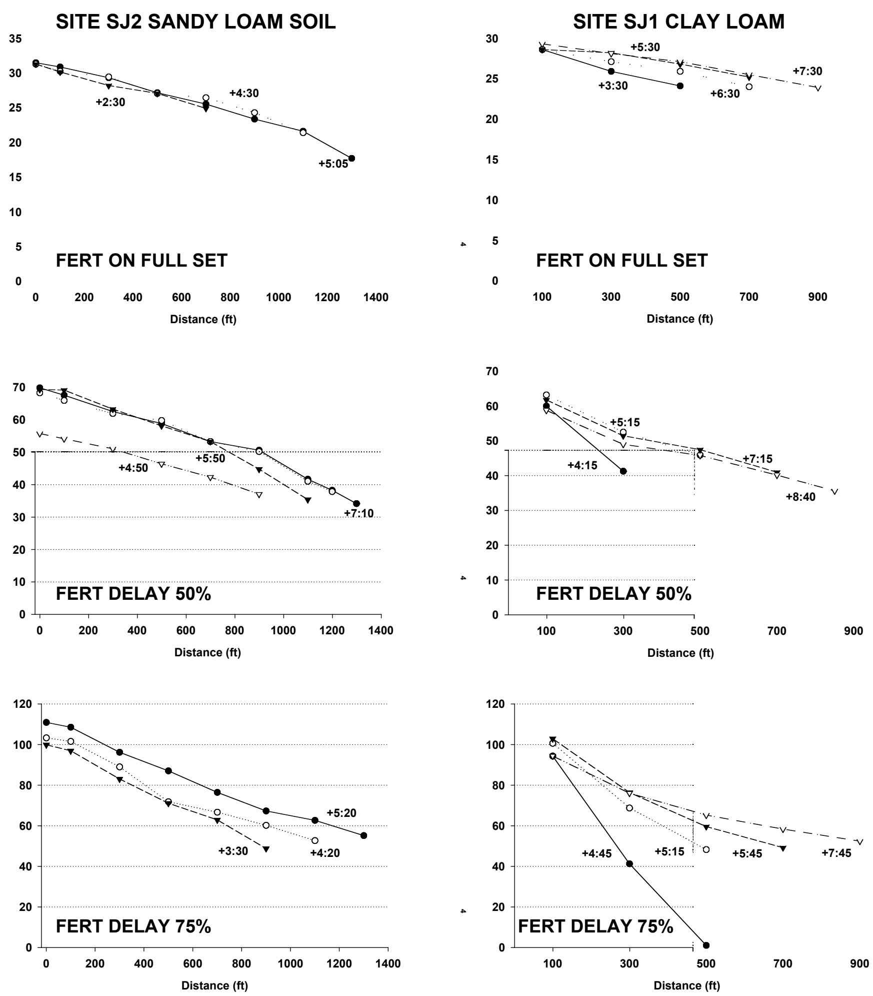
| Set/treatment | $NH^4$ concentration near (100 ft from) upper end of field, mg N/L | Decrease in $NH^4$ concentration down furrow, % per 100 ft |
|---|---|---|
| Site SJ1 – clay/clay loam | | |
| 1 – fert full | 30 | 2.4 |
| 2 – fert delay 50% | 61 | 4.8 |
| 3 – fert delay 75% | 100 | 5.6 |
| Site SJ2 – sandy loam/loam | | |
| 1 – fert full | 31 | 3.4 |
| 2 – fert delay 50% | 69 | 3.8 |
| 3 – fert delay 75% | 105 | 3.8 |

We have not yet calculated the total N application rate distribution across the field. It will reflect the combined effects of irrigation non-uniformity and ammonium N concentration decrease. Because the lower end of the field received less water (Table 1), and the concentration of the ammonium in that water was significantly lower (~50%) than at the upper end of the field, it is obvious that a very non-uniform N application rate was achieved. However, because we did not follow irrigation water recession (which proceeds from the top end of the field, thus increasing opportunity time on the bottom and decreasing it on the top), these data may overestimate the non-uniformity of the N application.

# FUTURE RESEARCH ACTIVITIES

- Complete calculation of N application rate along furrow and N distribution uniformity.
- Investigate use of commercial small-scale $NH_3$ injection systems to allow for better control of the rate and timing of injection in our experiments.
- Develop further the mathematical model of $NH_3$ volatilization loss.
- Conduct a similar set of tests at three or four farms in 2006. We will consider adding a border check-irrigated site and including a treatment at one site with urea-ammonium nitrate (UAN), which is less prone to volatilization losses of.

**Fig. 1. N concentrations in furrow water during fertigation with anhydrous ammonia injected during full irrigation set (top graphs), delayed until water advanced to approximately half the distance across field (center graphs), or delayed until water advanced approximately three-quarters of the distance across field (bottom graphs). Concentrations are shown for a range of times after initiation of irrigation. Distance (x axis) is from upper end of field.**



# Development of Lime Recommendations for California Soils

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## Introduction

Increasingly acid soils have been noted on soils of northern and central California by field agronomists and soil testing laboratories. These soils tend to be moderate to highly weathered or poorly buffered and/or acidified through ammonium based nitrogen fertilizers. Acidity levels below a pH of 5.60 are sufficient to impact crop growth and quality, dependent on the crop species and cultivar. Current lime recommendations for California utilizing the SMP buffer method are based on calibration models developed in the eastern United States on soils of distinctly different parent material, growing conditions, and cropping systems.

## Objectives

In 2002, a project was initiated to evaluate lime requirement calibration models for California soils selected from the San Joaquin Valley, North Coast, and Sacramento Valleys of California. Soils were selected from vineyards, tree crop, forage, and row crop areas, where commercial testing laboratories and agricultural consultants have noted low pH values. Soils were characterized for chemical and physical properties and the lime requirement assessed using a five-day neutralization/ incubation test and four buffer pH methods. An additional 21 soils were collected in 2004 on which to validate the lime recommendations developed on the initial set of 120 soils.

## Description

One hundred and twenty-one soils were collected in 2002 representing 19 counties of central and northern California. Sites included lettuce, lemon, heather, pistachio, watermelon, almond, tomato, onion, squash, potato, rice, grapes, peppers, pasture, and corn crops.

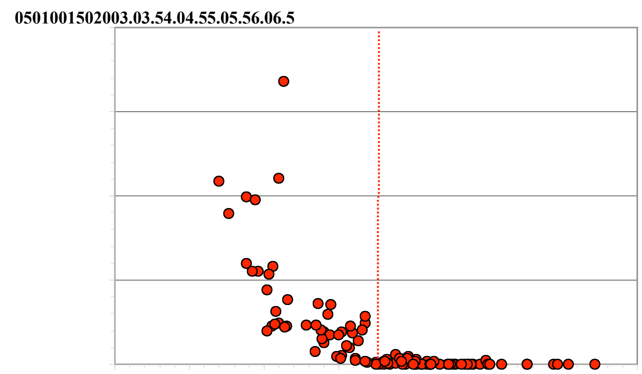
Soils were analyzed for: saturated paste moisture content; pH saturated paste method; saturated paste EC; pH (1:1) $H_2O$ method; pH (1:1) 0.01 M $CaCl_2$ method; KCl extractable Al; ammonium acetate extractable K, Ca, Mg, and Na; Olsen extractable $PO_4$-P, DTPA extractable Zn, Mn, Fe and Cu; cation exchange capacity; soil organic matter; and sand, silt and clay contents. Specific analyses were conducted in triplicate. Five reference soils from the North American Proficiency Testing (NAPT) program archives were included as quality assurance samples to authenticate the quality of the soil analyses. Soil lime methods-based buffer pH included: SMP buffer pH (Sims 1995,); a modified SMP method (50% strength) Adams Evans buffer pH (Adams, 1984); Mehlich buffer pH (Mehlich, et al, 1976); and Woodruff Buffer pH (Sims, 1996). All soils were evaluated for exchangeable acidity based on a modified five-day incubation with calcium hydroxide (Adams, 1962). A proposed additional lime buffer capacity method was add to the project in 2003, based on a proposed University of Georgia direct calcium hydroxide addition and subsequent determination of pH as described by Liu et al (2005). In 2004, an additional 22 acid soils were collected from across California on which to validate the proposed lime recommendation model.

## Results and Conclusions

Of the 120 soils collected, 22 had an initial soil pH (1:1) 0.01 M $CaCl_2$ method that exceeded 6.20, and thus deemed not appropriate for use in this study. Of the remaining 98 soils, soil pH (1:1) 0.01 M $CaCl_2$ results indicated 14 soils were less than 4.00, 39 of the soils were between 4.50 to 5.00, 42 had a pH in the range of 5.00 to 6.00 and three with a pH between 6.00 and 6.30. Results for soil KCl extractable Al, an indicator of strongly acid soils, indicated five soils had Al values exceeding 100 mg $kg^{-1}$, 26 soils in the range of 20 - 100 mg/kg Al, 37 soils with 1.0 - 20 mg $kg^{-1}$ Al, and the remaining 20 had concentrations less than 1.00 gm $kg^{-1}$ Al. Plotting pH (1:1) 0.01 M $CaCl_2$ against Al content indicates that Al concentrations become significant (> 2.0 mg $kg^{-1}$) for soils with a pH 0.01 M $CaCl_2$ below 4.80, Figure 1. For the saturated paste this is a pH of 5.10 and a pH (1:1) $H_2O$ of 5.60. Extractable Al concentrations increased dramatically with decreasing pH.

Soil saturated paste moisture content ranged from 19.8 - 69.3% indicating the soils evaluated ranged from loamy sand to clay in texture. Results for sand analysis indicate these soils were dominated by coarse textured materials with 50% of the soils having more than 47% sand by weight. Cation exchanged capacity (CEC) indicated that 50% of the soils were below 6.3 cmol $kg^{-1}$. Five-day lime incubation values ranged from 210 to 10,590 lbs $ac^{-1}$ with a median of 1380 lbs $ac^{-1}$ $CaCO_3$. Thirty soils had a five-day incubation lime rate of less than 1000 lbs $ac^{-1}$, 51 in a range of 1000 - 4000, lbs $ac^{-1}$ and 17 with a rate exceeding 4000 lbs ac-

**Figure 1. Relationship of soil pH (1:1) 0.01 M $CaCl_2$ and KCl extractable Al for 98 soils collected from central and northern California.**




A plot of five-day lime incubation rate ($CaCO_3$ lbs $ac^{-1}$) with pH (1:1) 0.01 M $CaCl_2$ indicates another unique area plot, Figure 2. Shown in the figure is salt pH 4.80 where Al concentrations exceeded 1.00 mg $kg^{-1}$. A plot of isolines of saturated paste moisture on this figure indicates that "general" ranges of five-day incubation lime rates can be further separated for a given pH by the saturated paste moisture. As an example a soil with 24% saturated paste moisture and a salt pH of 5.00 would have a lime application rate of 1400 lbs $ac^{-1}$, while a soil with an identical pH and 40% saturated paste moisture content would have a lime application rate of 3000 lbs $ac^{-1}$. These isolines for separating five-day lime incubation rates are only approximate as some soils (as indicated in the legend) fall outside the isolines demarcating their boundaries. Nonetheless, 81 of the 98 soils fall within the boundary areas, indicating that saturated paste moisture can be used as a co-variable in estimating lime requirements as determined by a five-day incubation.

This use of soil saturated paste moisture content in conjunction with pH is similar to a model used by the University of Illinois in the 1950s using soil texture classification and soil pH to estimate lime recommendations (citation).

Figure 2. Relationship of pH (1:1) 0.01 M $CaCl_2$ and five-day incubation lime rate for 98 California soils.

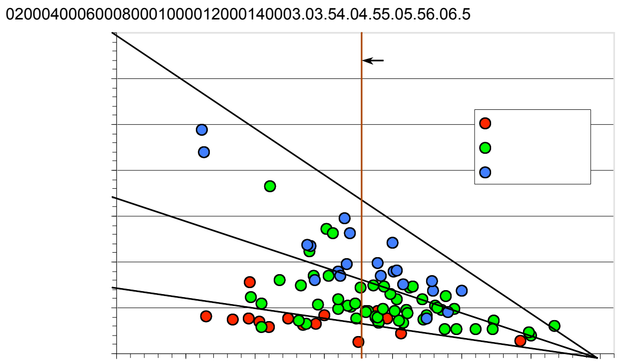
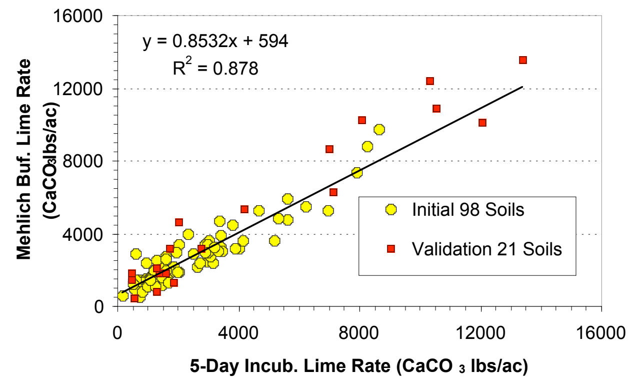



Figure 3. Comparison of Mehlich buffer lime recommendation and five-day lime incubation rate for 120 California soils.




Results for the SMP buffer method ranged from pH 5.45 to 7.45, with a median of 6.89. Based on reported SMP lime recommendation (Sims, 1996), the threshold SMP buffer pH for which no lime is required was 6.95. Using this recommendation model for SMP estimating lime, 46% of the California soils evaluated had no lime requirement. The five-day lime incubation rate on these same soils ranged from 125 - 1380 lbs $ac^{-1}$, with a median of 860 lbs $ac^{-1}$ $CaCO_3$. Generally these soils were poorly buffered and had less than 20 mg $kg^{-1}$ of extractable Al.

During 2003 and 2004 an additional 22 soils were collected from the San Joaquin Valley, North Coast and Sacramento Valleys of California for validating the principle models developed in phase I of the project. For the validation soils pH (1:1) 0.01 M $CaCl_2$ ranged from 3.19 to 5.75 with a median 4.42. Soil saturated paste moisture and CEC were identical to the original 98 soils database. KCl extractable Al indicated five soils had Al values exceeding 100 mg $kg^{-1}$, eight soils in the range of 20 - 100 mg/kg Al, eight soils with 1.0 - 20 mg $kg^{-1}$ Al. Five-day lime incubation lime rates ranged from 480 to 26,600 lbs $ac^{-1}$ with a median of 1940 lbs $ac^{-1}$ $CaCO_3$. The relationship between the five-day incubation and Mehlich lime rate is shown in Figure 3.
Figure 3. Comparison of Mehlich buffer lime recommendation and five-day lime incubation rate for 120 California soils.

## SUMMARY AND CONCLUSIONS

Two models were selected for predicting lime requirements for California soils. The first was based on soil pH (1:1) 0.01 M $CaCl_2$ and saturated paste moisture (application rate based on five-day incubation lime rate). The pH method is easily implemented and soil saturated paste is a routine analysis conducted in California agricultural testing laboratories. Lime rates were based on neutralization of soil acidity to a pH of 7.00 to a depth of six inches using 100% $CaCO_3$. The actual lime application rate would require adjustment as typical agricultural lime ranges from 60 - 80 Calcium Carbonate Equivalent (CCE). It is suggested that soils testing below a pH (1:1) 0.01 M $CaCl_2$ of 4.80, also be analyzed for KCl extractable aluminum, as additional lime may be needed to neutralize the added acidity. The lime rate determined using the following equation:

EQ1: Lime Rate lbs $ac^{-1}$ = 3960 + 112 (SP) - 1203 (pH) - 9.0 (Al)

where SP is the saturated moisture percentage in percent, pH is by the (1:1) 0.01 M $CaCl_2$, method and Al is KCl extractable Al in mg $kg^{-1}$. For every 100 mg $kg^{-1}$ of extractable aluminum an additional 900 mg $kg^{-1}$ $CaCO_3$ is required.

The second model recommended for estimating lime rate for California soils was based on the Mehlich buffer pH method. This model explained 87% of the variability in five-day incubation results. It has the advantage that only one additional soil test is needed and provides for the estimate of exchangeable acidity. The equation for acidity and determining lime application rate from the Mehlich buffer are as follows:

EQ2: $AC = (6.60 - \text{Mehlich Buf pH}) \times 4$

EQ3: $\text{Lime Rate lbs ac}^{-1} = ((0.10 \times (AC^2)) + AC) \times (2000 \times 0.446)$

In general there was very good agreement between the two models and the five-day incubation. The relative difference between the two models for a majority of the soils was generally within the lime rate error of estimation, which for these methods is approximately 240 lbs $ac^{-1}$ of 100% $CaCO_3$. Soils with high KCl extractable aluminum (Al > 100 mg $kg^{-1}$) were the exception with the Mehlich buffer indicating a much higher lime rate, similar to the amount listed for the five-day incubation method.

## Acknowledgment

Thanks goes to the staff, consultants and management of Western Farm Services, Dellavalle Laboratory, UCCE Service, A & L Western and Sunland Labs for their assistance in securing soils for this research project.

# Probability Distribution of Soil and Solution Partitioning Coefficients of Cadmium ($K_D$)

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## Abstract

The solid-to-solution partitioning coefficient ($K_d$) is an important parameter in assessing the environmental and health risks of potentially toxic metals in cropland soils. Ideally, $K_d$, the ratio of the total and solution concentrations of metal in soil, is determined under the field moisture conditions. In reality, the soil solution concentration is represented by the concentration in extracts of a given soil-to-water ratio. We used cadmium as an example to demonstrate the uncertainties in determining the soil solution Cd concentrations, thus the $K_d$. Results of extraction experiments showed that extracting the soils at the soil-to-water ratio of 1: 0.5 was able to result in soil Cd concentrations representative of the field moisture conditions. Under this circumstance, the Cd concentration in soil solution tends to be probabilistic and follows a normal distribution. The Cd $K_d$ probability distribution functions of two California cropland soils were generated. If $K_d$ is characterized in probabilistic terms, the risks of environmental and health harms of metals in the soils may be more appropriately assessed.

## Introduction

Trace elements such as Cd are ubiquitous in the natural environment. At the normal concentration ranges, the potentially hazardous trace elements do not pose a significant threat to human and eco-system health. Their levels in cropland soils, however, may become elevated through various agricultural activities such as fertilizer applications, irrigation, and pesticide sprays. The enrichments in the soils may lead to inadvertent transfer of trace elements through the food chain. The possible risks derived from the increasing amount of Cd in cropland soils have resulted in growing public health concerns for consumers.

In soil, Cd, like most trace elements, is not readily soluble. They are adsorbed by inorganic solid phases, organic matter and clays, associated with the primary minerals, or form insoluble precipitates. The behavior of trace elements in the soil-water-plant system is expected to be dependent on their chemical forms. Trace elements in the soil solution are of special interest as they are readily accessible to plants and mobile through the vadose zone to reach underground waters. Knowledge on the distribution of trace elements between the solid and solution phases are imperative for assessing environmental and health risks associated with the anthropogenic soil Cd.

Soils often are repositories of fugitive trace element pollutants such as Cd and serve as the starting point for their potential food chain transfer. In risk assessment and solute transport modeling, the trace element concentration in solution phase often is assumed to be in linear proportion to the total trace element concentration of the soil:

$$K_d = \frac{C_{Total}}{C_{Solution}} \qquad \text{[Eq. 1]}$$

where $K_d$ ($l\ kg^{-1}$) is the solid and solution phases partitioning coefficient and $C_{Total}$ ($mg\ kg^{-1}$) and $C_{Solution}$ ($mg\ l^{-1}$) are the total and solution concentrations of trace element of soils, respectively. The solution concentration is customarily determined as the concentration in the soil extract of a given soil-to-solution ratio such as l:10 (w/v). There is growing recognition that $K_d$ obtained in this manner may not be entirely representative, as the soil solution determined in this manner may not be realistic. On the other hand, the solution concentration is also dependent on the solid-to-solution ratio and the duration of equilibration. The plant roots from which the food chain transfer processes begin are hardly ever exposed to the trace element at such intense levels, mimicking the concentrations represented by the customarily solid-to-solution ratio at 1: 10 or even 1:5 (w/v). Under the normal circumstances, the solid-to-solution extraction ratios of 1:10 or 1:5 are inadequate to bring all of the soluble soil Cd into the solution phase. Consequently, the solution-to-solid phase distribution as characterized by $K_d$, is significantly affected by the soil-to-water ratio.

The chemical constituents of the soil solution are ideally determined by extracting soils at the field moisture level, as it is most reflective of the realistic situations. At the field moisture levels, the soils contain little free water. The outcomes will not always be consistent because the mass transfer likely is diffusion-limited and the equilibrium is localized around discrete metal-containing particles and only a small portion of the water can be extracted. Conceptually, the concentration of Cd in field soils should therefore be probabilistic in nature.

Customarily, the soil solution is obtained at the water-to-soil ratio when the mixture forms a homogeneous soil paste that is conceptually defined as the largest amount of water to be added without significantly changing the concentration of dissolved constituents of soil solution. The approach appeared to work well and provided consistent results if the constituents are readily soluble or the soils are heavy contaminated. The trace element concentrations obtained from the lower soil-to-water ratios are not representative of the realistic conditions in soils. If a limited quantity of a trace element is available for dissolution, a lower soil-to-water ratio (i.e. high water volume with respect to amount of soil, such as 1:10) will result in the dilution of the chemical in solution. At higher soil-to-water ratios (i.e. low water volume with respect to amount of soil, such as 1:1 and higher), relatively large amounts of soil mass are needed to obtain small volumes of extract. Under the circumstances, the mass transfer of Cd from solid-to-solution phase will be short-ranged and the equilibrium would be localized. In turn, the Cd concentrations in the extracted solutions would be probabilistic.

In this study, the Cd concentrations in soil solutions were determined from the extracts that represent different solid-to-solution ratios. Relationships between Cd concentrations in solution and solid phases were fitted into a linear Langmuir isotherm equation. The most appropriate soil-to-water ratio for determining the Cd concentration in soil solution was selected based on results from the batch extraction experiments. The probability distribution of the solution concentrations, hence the partitioning coefficient of Cd, were investigated in two California cropland soils.

### *Probability Distribution of Soil Solution Concentrations and $K_d$*

The distribution of Cd concentrations in soil solution was represented by 20 replicated measurements made at soil-to-water extraction ratio of 1:0.5 (w/v). Table 1 summarized the descriptive statistics characterizing the probability distributions of Cd concentrations for these two soils. The average soil solution Cd concentration of the Holtville clay loam and the Arlington sandy loam is 0.216 and 0.319 μg $l^{-1}$, respectively. The lower quartile and upper quartile for Holtville clay loam soil are 0.143 and 0.275 μg $l^{-1,}$ respectively. For the Arlington sandy loam soil, they are 0.258 and 0.370 μg $l^{-1}$, respectively.

**Table 1. Descriptive statistic of the distribution of Cd solution concentration in the two test soils.**

| Soil | Mean | Standard Deviation | Skewness | Standard Error Skewness | Kurtosis | Standard Error Kurtosis |
|---|---|---|---|---|---|---|
| Holtville Clay Loam | 0.216 | 0.0966 | 0.702 | 0.512 | 1.029 | 0.992 |
| Arlington Sandy Loam | 0.319 | 0.0908 | 0.327 | 0.512 | 1.434 | 0.992 |

The Cd concentrations of the soil solution for the Holtville clay loam and the Arlington sandy loam follow a normal distribution. The normality of the distribution was first evaluated based on the statistic description of skewness, kurtosis and their corresponding standard error. The calculated μ values (the skewness divided by its standard error and the kurtosis divided by its standard error) are less than 1.96. Therefore, the distribution of soil solution Cd concentrations in both soils follows a normal distribution with $p < 0.05$. The distribution is slightly skewed toward the lower values with relatively lower peak. The K-S (Kolmogorov-Smirnov) test indicated that the two tailed p values for Holtville clay loam and Arlington sandy loam are 0.936 and 0.961, respectively, indicating the normality of the distributions are significant.

The $K_d$ values for these two soils can be simply calculated according to Equation [1] by dividing the total Cd content of the soils by the soil solution Cd concentrations. The resulting data was fitted with a Gaussian distribution in which the probability distribution function is described as:

$$f(x) = a \cdot \exp\left[-0.5 \cdot \left(\frac{x - x_0}{b}\right)^2\right] \qquad \text{[Eq. 2]}$$

where f(x) is the probability correspondence of x, $x_0$ and b is the mean and standard deviation of the calculated $K_d$ values (Figures 1 and 2). The fit is good for both soils ($r^2 > 0.9$). The fitted $x_0$ values are close to the mean values of the 20 replicates and the b values are close to the standard deviation of the sample.

The average $K_d$ is 3,006 and 730 L $kg^{-1}$ for the Holtville clay loam and the Arlington sandy loam, respectively. The lower quartile and upper quartile for Holtville clay loam soil are 1,723 and 3,337 L $kg^{-1}$, respectively. For the Arlington sandy loam soil, they are 573 and 825 L $kg^{-1}$, respectively. There is one extreme value in each soil, resulting in greater skewness and kurtosis. The distributions of $K_d$ are considerably skewed than those of soil solution Cd concentrations. The p values of the K-S tests are 0.225 and 0.294 for the Holtville clay loam and the Arlington sandy loam, respectively. Hence, the distribution of $K_d$ in these two California cropland soils, while visibly skewed, can still be described by a normal distribution. In this manner, the solid and solution phase distribution coefficients of Cd in cropland soils may be expressed in probabilistic terms and be used to characterize the uncertainties related to the fate and transport of trace elements in soils. The probability distribution function of $K_d$:

For Holtville clay loam soil it is

$$f(x) = 0.416 \cdot \exp\left[-0.5 \cdot \left(\frac{x - 1187}{437}\right)^2\right] \qquad \text{[Eq. 2]}$$

For Arlington sandy loam soil it is:

$$f(x) = 0.353 \cdot \exp\left[-0.5 \cdot \left(\frac{x - 623}{134}\right)^2\right] \qquad \text{[Eq. 3]}$$

## Conclusions

1. The soil solution concentration of cadmium may be represented by the Cd concentrations of the 1:0.5 soil-to-water extraction ratios.
2. The soil solution concentrations and the resulting solid and solution partitioning coefficients, $K_d$, of the two cropland soils follow the normal distribution.
3. Based on the outcomes of this study, the distribution coefficients of Cd between the solid and solution phases may be expressed in probabilistic terms.

**Figure 1. Probability distribution of partitioning coefficient (Kd) of Cd in the Holtville clay loam soil.**

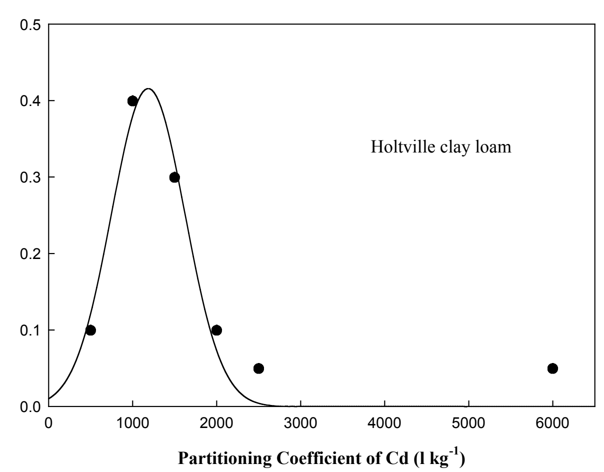
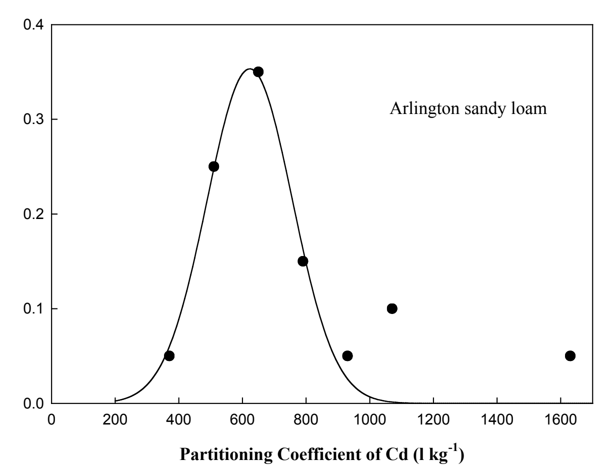



**Figure 2. Probability distribution of partitioning coefficient (Kd) of Cd in the Arlington sandy loam soil.**



# Crop Nitrate Availability and Nitrate Leaching under Micro-Irrigation for Different Fertigation Strategies

***Project Leaders***
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## Introduction

Microirrigation (microsprinklers, drip emitter, drip tape) has the potential for precisely applying water and fertilizer throughout a field both in terms of amount and location. This potential can result in higher yields and profit, reduced water costs, reduced fertilizer costs, and can also reduce leaching of chemicals to the groundwater.

Fertigation is the process of applying fertilizers through the irrigation water. The maximum potential field-wide uniformity of the applied fertilizer will reflect the uniformity of the applied or infiltrated water. For microirrigation systems, a recommendation frequently used for injection of fertilizer is to inject during the middle one-third or the middle one-half of the irrigation set time to insure a field-wide uniformity of applied fertilizer equal to that of the irrigation water. However, observations of grower practices revealed that injecting for a short period of time, i.e. one or two hours, is common. Under some circumstances, the timing and duration of short fertigation events might contribute to fertilizer leaching below the root zone.

## Project Objectives

1. To determine fertigation strategies for microirrigation systems using state-of-the-art modeling tools to improve water and nutrient use efficiencies and to reduce leaching of nitrates and other nutrients and chemicals.
2. To develop jointly a publication and slide show for our target audience, highlighting the recommendations using color graphics of two-dimensional simulation results to illustrate the effect of proposed fertigation strategies on the movement of nitrate for various microirrigation systems.

## Project Description

Various fertigation strategies for microirrigation systems were examined to improve water and nutrient use efficiencies and to reduce leaching of nitrates using the computer simulation model, HYDRUS-2D. Output of the model included the distributions of nitrate and soil water content and a mass balance of nitrate in different parts of the root zone. Model results were used to develop guidelines for proper fertigation management practices.

The model simulations were conducted in two phases. The first phase modeled nitrate movement in the soil for a nitrate-only fertilizer. The second phase modeled urea, ammonium, and nitrate movement of a urea-ammonium nitrate fertilizer (UAN 32) commonly used for microirrigation. The forms and concentrations of N of this fertilizer are urea N (16.4%), ammonium N (7.4%), and nitrate N (7.4%).

Phase 1 fertigation scenarios consisted of four different microirrigation systems, four soil types, and five fertigation strategies. Microirrigation systems were 1) SPR - microsprinkler (citrus); 2) DRIP - surface drip irrigation (grapes); 3) SURTAPE - surface drip irrigation using high-flow drip tape (strawberries); and 4) SUBTAPE - subsurface drip irrigation using low-flow drip tape (tomatoes). Soil types were 1) sandy loam; 2) loam; 3) silt clay; and 4) anisotropic silt clay. Fertigation strategies were 1) B - inject for two hours starting one hour after start of irrigation; 2) M - inject for two hours in the middle of the irrigation set; 3) E - inject for two hours starting three hours before cutoff of irrigation water; 4) M50 - inject during the middle 50% of the irrigation set time; and 5) C - inject continuously during the irrigation set.

Phase 2 fertigation scenarios consisted of two microirrigation systems, one soil type, and three fertigation strategies. Microirrigation systems were DRIP and SUBTAPE; soil type was loam; and fertigation strategies were B, E, and M50 scenarios. Selection of these scenarios was based on the Phase 1 results. Appropriate coefficients were incorporated into the HYDRUS-2D model to account for the hydrolysis of urea and the nitrification and adsorption of ammonium.

## RESULTS AND CONCLUSIONS

Phase 1 results were discussed in the 2004 FREP conference. Only Phase 2 results will be presented herein. Figure 1 shows the distributions of urea, ammonium, and nitrate for DRIP – B (fertigation for two hours near the beginning of irrigation) and Figure 2 shows the distributions for DRIP-E. Highlights are:

***Urea***

– At the end of the first irrigation (1.5 days), a band of urea was found near the periphery of the wetted pattern. Little or no urea was found near the drip line.

– A similar distribution occurred at the beginning of the next irrigation (3.5 days) and the start of the second fertigation event (3.54 days) except urea concentrations had slightly decreased with time.

– At the end of the second fertigation (3.63 days), the urea was distributed into two zones; one zone similar to that of 3.54 days and a highly concentrated zone near the drip line. The horizontal movement of urea near the drip line was about twice that of the vertical movement.

– At the end of the second irrigation (5.00 days), leaching had moved the urea away from the drip line to a band between 30 and 80 cm deep below the drip line and between 40 to 60 cm horizontally from the drip line.

– At the start of the third irrigation event (7.00), the distribution of urea was similar to that of 5.00 days, but with smaller concentrations.

– Urea distributions at the end of the last irrigation (26.00) and two days later (28.00 days) were similar to those of 5.00 and 7.00 days, indicating that no accumulation of urea with time had occurred in the soil profile.

***Ammonium***

– Ammonium was concentrated in the immediate vicinity of the drip for all times with little change in concentration due to fertigation and irrigation events (Fig. 1).

– The distribution of ammonium throughout the soil profile increased slightly with time to a depth of nearly 25 cm deep below the drip line and a horizontal distance of nearly 30 cm from the drip line.

– The relatively similar ammonium concentrations with time reflect a continuous supply of ammonium due to the fertigations and the hydrolysis of urea.

***Nitrate***

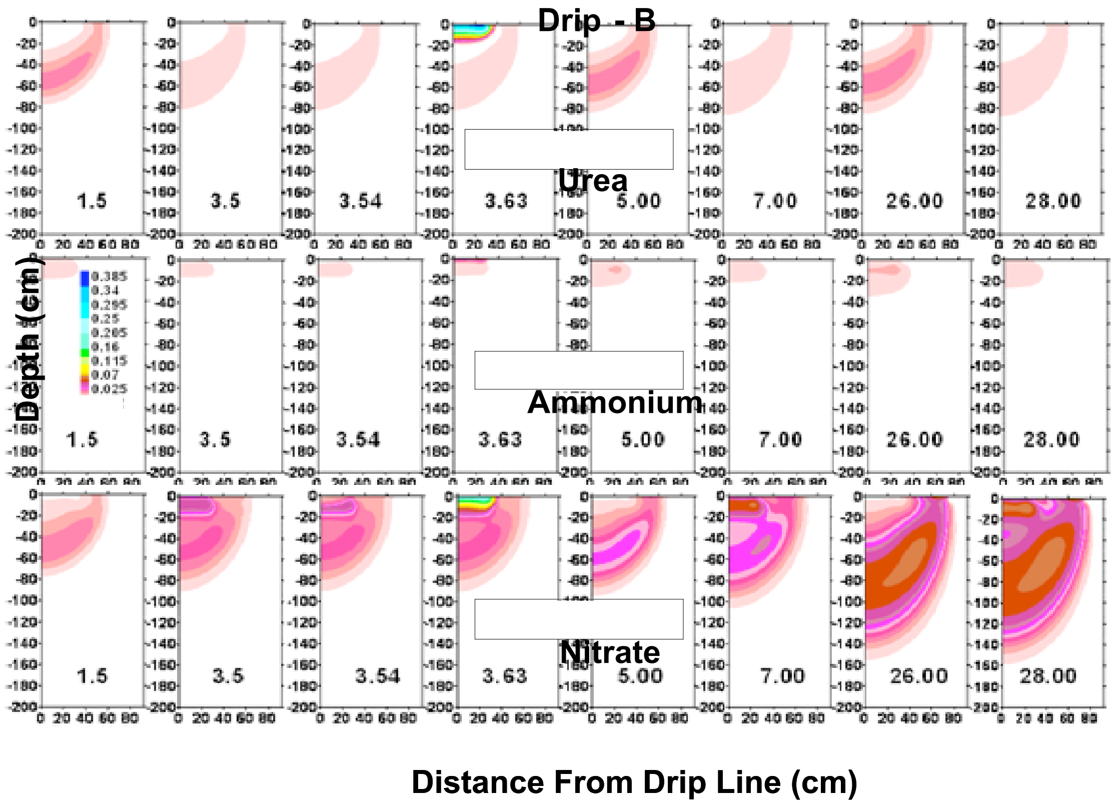
– At the end of the first irrigation event (1.5 days), most of the nitrate was distributed in a band near the periphery of the wetted area due to leaching during the remainder of the irrigation event (Fig. 1). Near the drip line, relatively small nitrate concentrations were found.

– The nitrate distribution at the beginning of the second irrigation (3.5 days) and at the start of the second fertigation event (3.54 days) showed a relatively uniform distribution throughout the wetted area. However, nitrate levels in the immediate vicinity of the drip line had increased since 1.5 days due to nitrification. The small areas of relatively high nitrate concentrations reflect the distribution of ammonium around the drip line.

– Similar nitrate concentrations were found for 3.5 days (start of second irrigation) and 3.63 days (start of the second fertigation event) except for the very high concentrations immediately adjacent to the drip line.

– By 5.00 days (end of irrigation), most of the nitrate had been leached from the vicinity of the drip line into a band extending over the periphery of the wetted area with relatively small concentrations near the drip line.

**Figure 1. Distributions of urea, ammonium, and nitrate with time between the first and second irrigation and at the end of the simulation periof for the B fertigation strategy. The numbers are the days from the start of the first irrigation.**




– By 7.00 days (start of the next irrigation), a relatively uniform nitrate distribution occurred throughout the wetted pattern with a distribution similar to that at 3.5 days, but with a deeper depth of movement and a slightly larger horizontal distribution. Near the drip line, nitrate concentration had increased compared to that of 5.00 days due to nitrification. The increased nitrate concentration near the drip line reflects the nitrification of the ammonium applied during the fertigation, but the relatively uniform nitrate distribution throughout the rest of the profile is probably due to a combination of plant uptake, nitrate leaching towards the edge of the wetted area, and the distribution of urea at that time, which due to hydrolysis and nitrification may have affected the nitrate distribution throughout that part of the profile.

– At the end of the last irrigation event of the simulation period (26.00 days), nitrate was distributed relatively uniformly throughout the wetted pattern except for the smaller concentrations near the drip line.

– By 28.00 days, a relatively uniform distribution of nitrate was found throughout the wetted pattern with nitrate concentrations increasing immediately near the drip line for reasons discussed earlier. Nitrate had moved down into the soil profile to nearly 150 cm deep below the drip line.

### *Mass Balance*

The mass balance of the B fertigation strategy showed no accumulation of urea occurred in the profile during the simulation period, indicating that the mass of urea converted to ammonium by hydrolysis equaled the mass applied. The mass of ammonium in the profile increased with time with only a slight change between irrigation events for all fertigation strategies, indicating that the sources supplying ammonium (fertilizer, urea hydrolysis) exceeded the sinks (plant uptake, nitrification). No leaching of ammonium and urea occurred.

Nitrate also accumulated with time for all fertigation strategies, indicating that sources supplying nitrate (fertilizer, nitrification of ammonium) exceed the sinks (plant uptake, leaching). The nitrate mass balance showed leaching percentages of 6.8 %, 2.6 %, and 5.2 % for the B, E, and M50 fertigation strategies, respectively. These leaching percentages were slightly smaller than those found for the Phase 1 study using a nitrate-only fertilizer.

***DRIP – E, M50***

Figure 2 shows the distributions for the DRIP – E (fertigation for two hours near the end of the irrigation). The hydrolysis and nitrification reactions had a similar effect on the concentrations of ammonium and nitrate. However, because the fertigation events occurred near the end of the irrigation, concentrations of urea and nitrated tended to remain near the drip line compared to the B strategy. For the M50 strategy (not shown), the urea and nitrate were more uniform distributions in the wetted pattern compared to the B and E strategies.

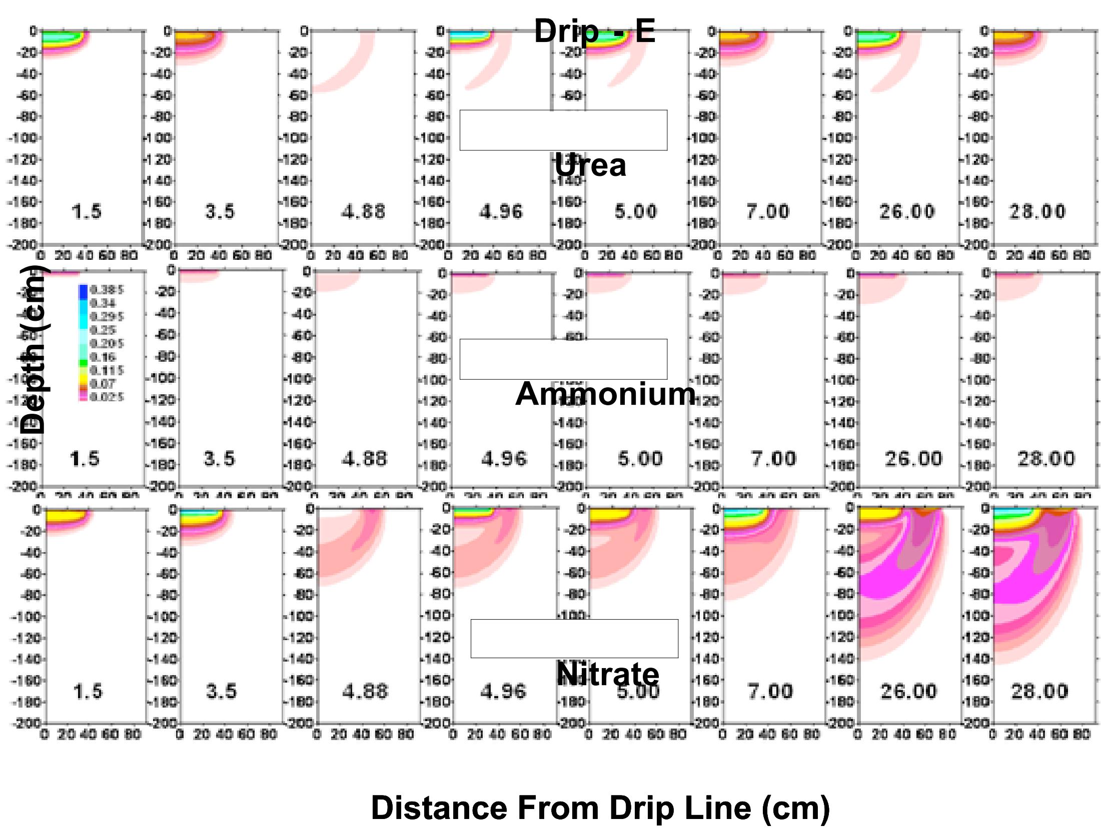
***SUBTAPE***

Results of the SUBTAPE simulations reflected the subsurface drip system with drip lines buried at 200 mm deep. However, the distributions of urea, ammonium, and nitrate (not shown) showed a range of results similar to those found in the DRIP simulations.

## Conclusions

The Phase 1 modeling showed nitrate concentrations and distributions to be sensitive to the fertigation strategies. However, these simulation results indicated that because of hydrolysis and nitrification, nitrate distributions in the soil profile were less sensitive to the fertigation strategy. For example, the B strategy resulted in most of the nitrate leached away from the drip line for a nitrate-only fertilizer. However, because of the urea and ammonium in the UAN 32 fertilizer, relatively high nitrate concentrations occurred near the drip line as well as in the rest of the wetted pattern.

**Figure 1. Distributions of urea, ammonium, and nitrate with time between the first and second irrigation and at the end of the simulation periof for the E fertigation strategy. The numbers are the days from the start of the first irrigation.**



# Site-Specific Variable Rate Fertilizer Nitrogen Application in Cotton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## Introduction

The use of automatic guidance, yield monitors, global positioning systems, remote sensing, and other attributes of site-specific crop management is increasing in California. California farmers who have adopted yield monitoring and mapping technology have frequently observed a high level of yield variability in their fields. One of the key criteria for the adoption of site-specific management is that growers be able to interpret these yield maps based on their knowledge of the field, and use this interpretation to improve their management and enhance profitability. However, final adoption of the technology will depend on whether the amount of increased revenue, resulting either from increased yields or reduced inputs, will be sufficient to offset the increased costs associated with the technology itself.

One of the most promising site-specific management practices is variable rate fertilizer application. In particular, variable rate application of fertilizers, especially fertilizer nitrogen, has been extensively studied in Midwestern cropping systems. Scientific investigations of the profitability of variable rate nitrogen application in the Midwest have produced equivocal results, with some investigations indicating a profit and others not. Much of the work in the upper Midwest has been motivated by regulatory concerns associated with potential contamination of ground and surface waters. Variable rate nitrogen application offers the potential for increasing profitability and reducing environmental effects of crop production if the increased costs associated with the practice can be offset by reduced input costs and/or reduced regulatory pressure.

Some cotton growers in California have in the last few years begun exploring the use of variable rate nitrogen application. Results of FREP-supported research of Rains, Travis, and Hutmacher indicate that in some cases current nitrogen fertilization practices in California cotton production may not maximize fertilizer-use efficiency. The application of nitrogen fertilizer at a site-specific rate may provide the opportunity for the grower to increase profits and maintain economic viability. At the same time, it provides the opportunity to demonstrate to the public and to regulatory agencies that the agricultural industry can use voluntary methods to reduce potential environmental contamination resulting from inputs to crop production systems.

The experiments carried out in this research project focus on using high spatial precision bulk data (yield maps, remotely sensed images, and soil $EC_a$ values obtained from EM38 or Veris instruments) together with soil nitrate levels in the top two feet, obtained from soil cores taken through a directed sampling plan, to determine variable application rate in the first N application at layby. The experiments have been carried out in commercial fields, and the other aspects of crop management are the same as that of the rest of the field. In particular, any additional N applications based on petiole sampling and/or other information are made at a uniform rate in the same manner as the rest of the field. Each experiment is carried out as a randomized complete block design with four levels: variable N rate, low fixed N rate control, nominal fixed N rate, and high fixed N rate. The low fixed N rate control is calculated to maintain a total soil N level of 50 lbs./acre. This rate provides an adequate control without forcing the cooperating grower to sustain an unacceptable economic loss. The nominal fixed rate treatments are at high and low rates used by the grower in his own production. The variable rate treatment is applied at a rate determined by an application rate map constructed according to soil productivity and estimated residual available N. Where salinity is high, this dominates bulk EC measurements. In California fields where salinity is not a factor, $EC_a$ generally is a reflection of soil clay content (Rhoades and Corwin, 1990). In any case, variations in $EC_a$ often can be interpreted as indicating variations in soil properties within a field. We use data from bulk EC and yield maps or remote sensing data from the previous year or years to develop a directed soil sampling plan. This sampling plan attempts to sample the field at approximately the same intensity as would a grower using traditional fixed N rate management.

## Specific Objectives

The overall objective is to determine whether variable rate nitrogen application is economically justified in California cotton production and, if so, to determine a practical method for implementing it. Specific objectives are:

1. Develop a practical method for creating variable rate fertilizer nitrogen application maps based on existing yield maps, remotely sensed NDVI images, and/or soil bulk electrical conductivity maps and soil nitrate N levels obtained through directed preseason sampling.
2. Conduct replicated experiments in large (typically quarter section) commercial fields in which the treatments are variable rate fertilizer application, fixed rate fertilizer application, and control.
3. Conduct a partial budget economic analysis based on established methods to determine the economic viability of variable rate fertilizer application for California cotton production. Determine the breakeven acreage at which this method is profitable and the payoff period for purchase of equipment, as well as the breakeven custom rate.

## Results

### *Sampling plan*

The sampling plan (devised in the first year and used throughout the experiment) was based on the rule of thumb that was used for a long time in cotton production and confirmed by recent FREP-sponsored research: that 60 lbs. of N per acre is required for each bale per acre of cotton production. With this objective, the plan was developed to estimate the yield potential and the available N in each location of the field. The previous year's yield was used to divide the field into zones. Since the principal source of lost yield in these fields was salinity, yield potential was estimated based on soil EC. Residual soil N was estimated based on soil samples. The specific sampling plan is as follows.

1. Based on the previous year's yield map, or an NDVI map if the yield map is unavailable, divide the field into three zones: high yield, medium yield, and low yield.
2. Select three widely scattered areas in each zone and extract soil samples from each of these areas (a total of 9). Obtain available N values for each sample.
3. Obtain an $EC_a$ map of the field (assuming salinity or sodicity is the major source of yield loss).
4. Estimate potential yield in different zones of the field based on visual inspection of the yield and $EC_a$ maps.
5. Calculate applied N based on potential yield and residual data for each zone.

Fig. 1 Yield map showing three yield classes and soil sample locations stratified by yield class.

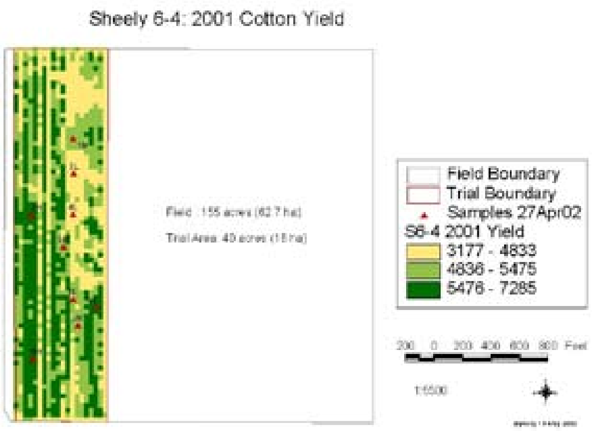



Fig. 2. Estimated residual nitrate N based on interpolated soil samples

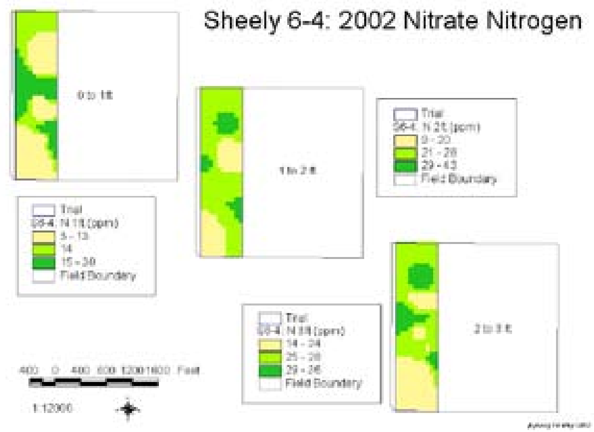



Fig. 3. Bulk soil EC maps.

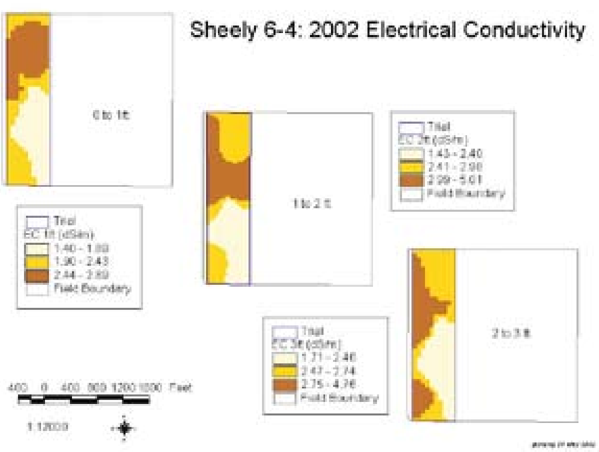
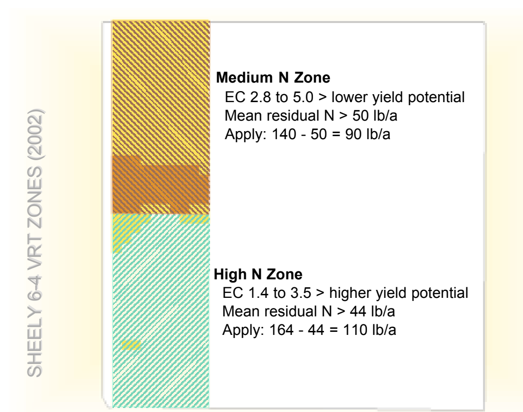



Fig. 4. Variable N rate zones based on estimated residual N and soil bulk EC.




Figures 1 through 3 show the yield, interpolated nitrogen, and bulk soil EC maps for one of the experimental fields. In this example only the test area is shown, but normally the analysis would be carried out for the whole field. The nitrogen zones are shown in Figure 4. In this particular example there were only two zones, but in general we have used three zones. It must be emphasized that the objective in our method is not to determine the statistically optimal application pattern using advanced methods, but rather to determine a reasonable pattern using the same methods as a grower would use.

The experiments were carried out in three fields in each of three years, 2002, 2003, and 2004, at farms in the southern San Joaquin Valley (Fresno and Kings Counties). The data were first analyzed for differences in yield among treatments. In the nine experiments there was no significant difference in any of the treatments. This suggests that although in principle the VRT approach could result in increased yields through more fertilizer being applied to high yield potential areas, we would expect that the more common situation would be a variation in rate due to reducing N application in low yield potential areas. Therefore, an increase in profitability must come from a savings in fertilizer costs sufficient to offset the costs associated with the VRT program. Economic analysis was completed for the 2002 data and is still being carried out for the 2003 and 2004 data. In 2002, the savings in fertilizer expenditures were substantial. Table 1 shows the percent reduction in midseason nitrogen fertilizer expenditures that is obtained through the VRT program at each of the test sites. There is a substantial reduction at each site.

**Table 1. Percent reduction in midseason nitrogen application costs, in comparison with the fixed rate treatment used on the rest of the field, at each of the sites.**

| Sheely | Woolf | McKean |
|---|---|---|
| -32.73% | -44.69% | -23.29% |

The question of increased costs associated with the VRT program is a subtle one and depends on how these costs are spread over other operations. This in turn depends on the size of the farm, on the other crops grown on the farm and whether they can also be fertilized according to a VRT program, whether a VRT program can be developed for other nutrients besides nitrogen, as well as for other inputs such as soil amendments and pesticides, and for how many years the grower can use the VRT equipment before it becomes obsolete. In order to obtain a conservative estimate of the cost, we have carried out a partial budget analysis that is summarized in Table 2.

We assumed that the sampling and mapping costs were fixed on a per acre basis, while the per acre equipment costs declined with increased acreage (Fig. 5). As indicated in the table, when all of the costs are assigned to a single quarter section field (the most conservative possible assumption), the VRT program does not pay for itself. The profitability of the program therefore depends on how many fields and how many operations the grower can implement the program on per unit of equipment. For simplicity, if we assume that the same number of fields can be managed with both one fertilizer rig and one cotton picker, then the decline in cost differential as a function of size is shown in Fig. 6. The breakeven point is reached at a farm size of about 500 acres per unit of equipment.

In reality, the situation is more complex since the number of fields per fertilizer rig is different from the number per picker. The primary contribution to equipment expense is the cost of the yield monitor. At 480 acres, the VRT program

**Table 2. Partial budget analysis of VRT program on each of the three farms, assuming that the equipment is depreciated over five years.**

| | Sheely | | Woolf | | Mc Kean | |
|---|---|---|---|---|---|---|
| OPERATION | Fixed | Variable | Fixed | Variable | Fixed | Variable |
| | $/acre | | | | | |
| Soil Samples | 2.64 | 3.18 | 2.64 | 3.18 | 2.64 | 3.18 |
| Recommendation Map | | 2.00 | | 2.00 | | 2.00 |
| Fertilizer | 29.48 | 21.40 | 29.13 | 18.09 | 49.73 | 39.27 |
| TOTAL FERTILIZER COST/ACRE | 32.12 | 26.58 | 31.77 | 23.27 | 52.37 | 44.45 |
| Operating Interest | 1.16 | 0.98 | 1.15 | 0.85 | 1.89 | 1.61 |
| TOTAL OPERATING COST/ACRE | 33.29 | 27.56 | 32.92 | 24.12 | 54.26 | 46.06 |
| CASH OVERHEAD: | | | | | | |
| Property Taxes | 3.68 | 4.19 | 3.68 | 4.19 | 3.68 | 4.19 |
| Property Insurance | 2.48 | 2.83 | 2.48 | 2.83 | 2.48 | 2.83 |
| Investment Repairs (Yield Monitor) | | 0.81 | 0.00 | 0.81 | 0.00 | 0.81 |
| TOTAL CASH OVERHEAD | 6.16 | 7.84 | 6.16 | 7.84 | 6.16 | 7.84 |
| TOTAL CASH COSTS/ACRE | 39.45 | 35.40 | 39.08 | 31.96 | 60.42 | 53.90 |
| NON-CASH OVERHEAD: | | | | | | |
| Yield Monitor | 0.00 | 5.59 | 0.00 | 5.59 | 0.00 | 5.59 |
| Equipment | 66.66 | 81.60 | 66.66 | 81.60 | 66.66 | 81.60 |
| TOTAL NON-CASH COSTS/ACRE | 66.66 | 87.18 | 66.66 | 87.18 | 66.66 | 87.18 |
| TOTAL COSTS/ACRE | 106.11 | 122.58 | 105.74 | 119.14 | 127.08 | 141.08 |

Fig. 5. Fixed and declining costs of the VRT technology.

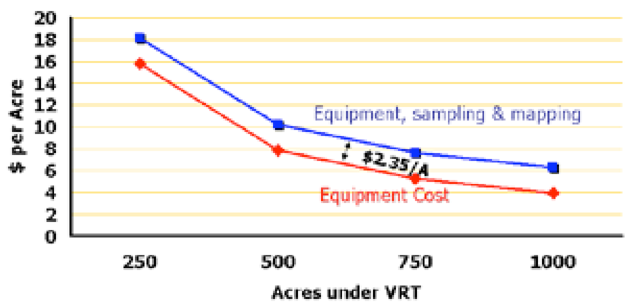
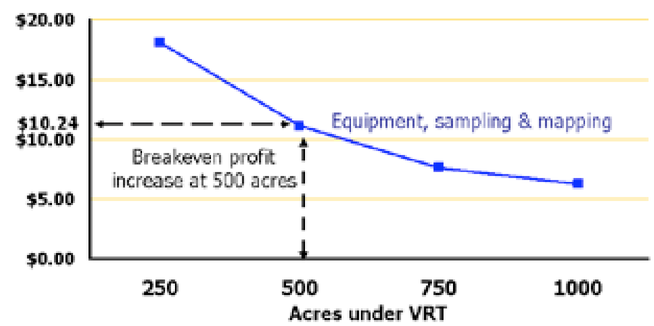



Fig. 6. Costs of VRT and fixed rate program as a function of farm size per unit of equipment. (fertilization plus yield monitoring).




is approximately equal to the fixed rate program. Therefore, variable rate fertilization should be profitable in the San Joaquin Valley if the farmer does one of the following: (1) manage more cotton fields than three quarter sections for each piece of equipment; (2) manage other cotton operations besides nitrogen fertilization using the VRT controller; (3) manage and harvest other crops besides cotton using the VRT equipment; or (4) use the equipment for more than five years. As the cost of yield monitors and controllers declines, which it is likely to do, the VRT program will become more profitable.

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